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STATISTICAL METHOD FOR STUDYING THE BEHAVIOR OF AN ENSEMBLE OF CHARGED PARTICLES UNDER THE INFLUENCE OF THEIR INHERENT MAGNETIC FIELD

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The stationary solutions for the statistical distribution function of the charged particles in a discharge in an ionized gas contracting about its own axis of symmetry under the influence of the inherent magnetic field are given. An isothermal plasma at a very high temperature is considered (completely ionized gas). An exact solution is carried out in the case of cylindrical symmetry. The density distribution depends on an arbitrary constant C which is determined by the experimental conditions. At large r the solution has the asymptotic form $\frac{1}{r^4}$.

It is the purpose of this paper to point out the existence of stationary solutions for the statistical distribution function for particles in a gaseous discharge which is constrained about its own axis of symmetry only by its inherent magnetic field. In [1] a pulsed discharge was considered and the expansion of the beam, observed experimentally, was considered interms of oscillations about the equilibrium configuration.

It will be assumed below that the temperature of the gas is sufficiently high so that it may be considered completely ionized. Consequently, in this work we will not take into account effects due to diffusion of neutral atoms in the plasma.

We will make use of the relativistic statistical equations for an ensemble of charged particles moving under the influence of the inherent magnetic field in the form given by S. Titeica.

Using a rationalized Gaussian system of units and introducing the anti-symmetric electromagnetic field tensor $B^{\mu\nu}$ we obtain the equations in the following form [2]:

$$\frac{\partial}{\partial x^\mu}(\xi^\mu F_{1,2}) + \frac{e_{1,2}}{m_{1,2}} B^{\mu\nu}\xi_\nu \frac{\partial F_{1,2}}{\partial \xi^\mu} = 0, \tag{1}$$

$$B_{\mu\nu} = \frac{\partial A_\mu}{\partial x^\nu} - \frac{\partial A_\nu}{\partial x^\mu}, \tag{2}$$

$$\Box A^\mu = -j^\mu, \tag{3}$$

where ξ^μ is the four-dimensional velocity vector; $F_{1,2}$ are the distribution functions for ions (F_1) and electrons (F_2) and j^μ is the four-dimensional vector associated with the current of charged particles.

We shall solve this integrodifferential equation for a stationary isothermal distribution with axial symmetry and carry out all calculations in the nonrelativistic approximation inasmuch as the thermal velocities are still rather small at the temperatures being considered.

We may note that Eqs. (1), (2) and (3) yield solutions of Class C_2 and consequently we may go directly to a cylindrical coordinate system.

The field $B^{\mu\nu}$ may be expressed in terms of the components of the four-vector A^{μ} which is a solution of Eq. (3) where the current is given by the sum of the currents due to ions and electrons:

$$j^{\mu}(r) = \int \xi^{\mu} [e_1 F_1(r, \xi^r, \xi^z, \xi^{\varphi}) + e_2 F_2(r, \xi^r, \xi^z, \xi^{\varphi})] d^3\xi. \tag{4}$$

Solving the wave equation (Poisson's equation for a stationary state), we find

$$A^{\mu}(r) = -\int \frac{\xi^{\mu}[e_1 F_1(r', \xi^r, \xi^z, \xi^{\varphi}) + e_2 F_2(r', \xi^r, \xi^z, \xi^{\varphi})]}{r_{pp'}} \times d^3r' d^3\xi, \tag{5}$$

where

$$r_{pp'} = \sqrt{r^2 + r'^2 - 2rr' \cos(\varphi - \varphi') + (z - z')^2};$$

whence

$$B_{12} = \int \left[r \cdot \frac{\partial}{\partial r}\left(\frac{1}{r_{pp'}}\right)(\xi^{\varphi} r') - \frac{\partial}{\partial \varphi}\left(\frac{1}{r_{pp'}}\right)\xi^r \right] \times \{\ldots\} d^3r' d^3\xi,$$

$$B_{13} = \int \left[\frac{\partial}{\partial r}\left(\frac{1}{r_{pp'}}\right)\xi^z - \frac{\partial}{\partial z}\left(\frac{1}{r_{pp'}}\right)\xi^r \right] \times \{\ldots\} d^3r' d^3\xi,$$

$$B_{23} = \int \left[\frac{\partial}{\partial \varphi}\left(\frac{1}{r_{pp'}}\right)\xi^z - \frac{\partial}{\partial z}\left(\frac{1}{r_{pp'}}\right)\xi^{\varphi} \right] \times \{\ldots\} d^3r' d^3\xi,$$

$$B_{14} = -\int \frac{\partial}{\partial r}\left(\frac{1}{r_{pp'}}\right) \times \{\ldots\} d^3r' d^3\xi,$$

where

$$\{\ldots\} = e_1 F_1(r', \xi^r, \xi^z, \xi^{\varphi}) + e_2 F_2(r', \xi^r, \xi^z, \xi^{\varphi}).$$

It is apparent that in the case of cylindrical symmetry, the functions $F_{1,2} = F_{1,2}(r, \xi^r, \xi^z, \xi^{\varphi})$ are independent of φ, and the derivatives with respect to φ and z of the function $(1/r_{pp'})$ are odd functions of φ and z and vanish in the integration; the same applies to the quantity ξ^{φ} if it is assumed that the average value of ξ^{φ} is zero. We may note that in this case B_{12}, B_{23}, B_{24}, and B_{34} vanish while B_{13} is equal to

$$B_{13} = \int \frac{-r + r' \cos(\varphi - \varphi')}{r^3_{pp'}} \xi^z \{\ldots\} r' dr' d\varphi' dz' d^3\xi.$$

In considering B_{14} we obtain a similar expression in which the quantity ξ^z is replaced by 1.

Integrating with respect to z' and φ' and assuming that $B_{13} = B^{13}$, while $B_{14} = -B^{14}$, we obtain

$$B^{13} = -\frac{4\pi}{r}\int_0^r r'dr' \int \xi^z \{e_1F_1 + e_2F_2\}\, d^3\xi = -H_\varphi,$$
$$B^{14} = -\frac{4\pi}{r}\int_0^r r'dr' \int \{e_1F_1 + e_2F_2\}\, d^3\xi = -E_r. \qquad (6)$$

Equation (1) assumes the form:

$$\xi^r \frac{\partial F_{1,2}}{\partial r} + \frac{e_{1,2}}{m_{1,2}}(E_r - \xi^z H_\varphi)\frac{\partial F_{1,2}}{\partial \xi^r} + \frac{e_{1,2}}{m_{1,2}}\xi^r H_\varphi \frac{\partial F_{1,2}}{\partial \xi^z} = 0, \qquad (7)$$

where E_r and H_φ are determined by the expressions given in (6).

Separating variables

$$F_{1,2} = f_{1,2}(r)\, g_{1,2}(\xi^r, \xi^z, \xi^\varphi),$$

we attempt, first of all, to find the solution which satisfies the condition $e_1f_1 + e_2f_2 = 0$. However, if we consider ions with charge equal and opposite to that of the electron,* $f_1 = f_2$; with this additional condition, the system of equations given in (7) becomes overdetermined.

Now, as will be apparent in the following, if we transform to a reference system in which the velocities of both types of particles have the same absolute value, the equations for f_1 and f_2 become the same; thus, if the initial conditions are the same [$f_1(0) = f_2(0)$], both functions become identical.

By virtue of this condition E does not appear in the equations.

Thus

$$\frac{1}{H}\cdot\frac{1}{f}\frac{\partial f}{\partial r} + \frac{e}{m}\left(-\frac{\xi^z}{\xi^r g}\frac{\partial g}{\partial \xi^r} + \frac{1}{g}\frac{\partial g}{\partial \xi^z}\right) = 0, \qquad (8)$$

whence it follows

$$\frac{1}{H}\cdot\frac{1}{f}\frac{\partial f}{\partial r} = \lambda,$$
$$-\frac{1}{\xi^r}\cdot\frac{\partial g}{\partial \xi^r} + \frac{1}{\xi^z}\cdot\frac{\partial g}{\partial \xi^z} = -\lambda\frac{m}{e}\frac{1}{\xi^z}g. \qquad (9)$$

In the equation for g the variables separate immediately: $g = A(\xi^r)B(\xi^z)$.

$$\frac{dA}{d\xi^r} = -\mu\xi^r A,$$
$$\frac{dB}{d\xi^z} = -\mu\left(\xi^z + \frac{\lambda}{\mu}\frac{m}{e}\right)B. \qquad (10)$$

As a result we obtain

$$A = C_1 e^{-\frac{\mu}{2}(\xi^r)^2},$$
$$B = C_2 e^{-\frac{\mu}{2}(\xi^z - v)^2}, \qquad (11)$$

* The case of hydrogen isotopes.

where C_1 and C_2 are arbitrary functions of ξ^φ and $v = -\frac{\lambda}{\mu}\frac{m}{e}$.

Thus,

$$g = Ce^{-\frac{\mu}{2}\left[(\xi^r)^2 + (\xi^z - v)^2 + \xi_\varphi \xi^\varphi\right]} \tag{12}$$

Here we have introduced in the exponential the square of the φ-component of the vector velocity (ξ^φ) in order to form the square of the difference of the vectors, $\underline{\xi}$ and $\underline{v}$, which is invariant under reversal of the coordinate system. *

We take the constant C to be equal to $\left(\frac{\mu}{2\pi}\right)^{3/2}$. This choice of normalization is not arbitrary, although it may seem so at first glance, because it is easily shown that if there is any additional factor in $\underline{g}$ the spatial part of the distribution function will contain the same factor to the -1 power and thus the arbitrary factor in $\underline{g}$ does not appear in the distribution function.

Under these condtions v_1 is recognized as the macroscopic ion velocity.

$$v_1 = \int \xi^z g_1 d^3\xi. \tag{13}$$

Finally, μ assumes the value $\frac{m}{kT}$, where T is the plasma temperature and $\underline{k}$ is the Boltzmann constant.

Thus, the equation for f(r) assumes the following form:

$$\frac{1}{f}\frac{df}{dr} = -\frac{4\pi e^2 v_1 (v_1 - v_2)}{kT}\frac{1}{r}\int_0^r f(r')\, r'\, dr', \tag{14}$$

where v_2 denotes the electron velocity.

If $v_2 = -v_1$** and I denotes the total current in the plasma, then $\frac{I}{2}$ will be the ion current and Eq. (14) is written in the form:

$$\frac{1}{f}\frac{df}{dr} = -\frac{2\pi I^2}{n^2 kT}\frac{1}{r}\int_0^r f(r')\, r'\, dr'. \tag{15}$$

Introducing the notation $K = \frac{2\pi I^2}{n^2 kT}$ and differentiating (15), we obtain

$$\frac{d}{dr}\left(r\frac{f'}{f}\right) = -Kf \cdot r. \tag{16}$$

Making the substitution

$$f = e^u \tag{17}$$

we obtain the equation

$$\frac{d}{dr}\left(r\frac{du}{dr}\right) + Ke^u r = 0. \tag{17'}$$

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* See the appendix.

** We choose the reference system in such a way that the equation for f_2 is identical to the equation for f_1. By a transformation of coordinates we can return to the original system.

Using (3) and introducing the substitution

$$x = r^2 e^u \quad \text{and} \quad y = r\frac{du}{dr}, \tag{18}$$

we obtain the equation

$$\frac{dy}{dx} = -\frac{K}{y+2}, \tag{19}$$

the implicit solution of which has the form

$$y^2 + 4y + 2A = -2Kx.$$

Returning to the variables u and r we obtain the equation

$$r^2\left(\frac{du}{dr}\right) + 4r\frac{du}{dr} + 2A = -2Kr^2e^u, \tag{20}$$

which, in conjunction with Eq. (17') is easily recognized as the Ricatti equation:

$$u'' - \frac{u'}{r} - \frac{1}{2}(u')^2 - \frac{A}{r^2} = 0. \tag{21}$$

Denoting $u = -2\ln w + \ln B$ where B is a constant which is to be determined, we may write Eq. (21) in the following form:

$$w'' - \frac{w'}{r} + \frac{A}{2r^2}w = 0. \tag{22}$$

The general solution of this Euler equation is of the form

$$w = C_1 r^{\alpha_1} + C_2 r^{\alpha_2}; \quad \alpha^2 - 2\alpha + \frac{A}{2} = 0. \tag{23}$$

Thus:

$$u = -2\ln(C_1 r^{\alpha_1} + C_2 r^{\alpha_2}) + \ln P. \tag{24}$$

To determine the constant B we substitute the value of u from Relation (24) in Eq. (17'):

$$-2C_1C_2 r^{\alpha_1+\alpha_2-1}(\alpha_1^2 + \alpha_2^2 - 2\alpha_1\alpha_2) = -KrB.$$

Equation (22) has only one singular solution for u

$$u_{sing} = -2\ln[r(C_1 + C_2 \ln r)] + \ln\frac{2C_2^2}{K}, \tag{25}$$

which does not satisfy the original Eq. (15) for f. Hence for $f = e^u$ we have

$$f = \frac{4(2-A)}{K}\Big/\left(Cr^{\alpha_1} + \frac{1}{C}r^{\alpha_2}\right)^2, \tag{26}$$

where $C = \sqrt{\frac{C_1}{C_2}}$.

Thus the solution depends on two arbitrary constants A and C and the exponents are related by the conditions

$$\alpha_1 + \alpha_2 = 2, \quad \alpha_1 \cdot \alpha_2 = \frac{A}{2}.$$

We shall determine one of these two constants, requiring that our solution satisfy the original equation.

For r = 0 we find:

$$\lim_{r\to 0}\frac{r}{f}\frac{df}{dr}=\lim_{\varepsilon\to 0}\int_0^{\varepsilon} fr\,dr. \tag{27}$$

Whence it follows that one of the exponents (α) is zero and the other is necessarily equal to 2 so that the constant $A = \alpha_1\alpha_2$ vanishes and the final calculation yields

$$f=\frac{8}{K}\Big/\left(Cr^2+\frac{1}{C}\right)^2. \tag{28}$$

Finally, the normalization condition

$$\int_0^{\infty} fr'\,dr'=\frac{n}{2\pi} \tag{29}$$

(n is the number of ions per unit length of the discharge chamber) yields

$$\frac{4}{K}=\frac{n}{2\pi}, \tag{30}$$

and since, according to (15), $K=\frac{2\pi I^2}{n^2kT}$, we arrive at the relation given by L. V. Kurchatov [1]:

$$T=\frac{I^2}{4nk}. \tag{31}$$

Actually we should integrate with respect to r over the limits from 0 to R, where R is the radius of the tube in which the discharge takes place. These results will apply only for sufficiently large C when the density of ions (f) close to the inner wall of the tube, where the temperature should not exceed a given limit, becomes very small. In this case K assumes the value $K=\frac{8\pi}{n}\left(1-\frac{1}{C^2R^2+1}\right)$ and the quantity $T=\frac{I^2}{4nk\left(1-\frac{1}{C^2R^2+1}\right)}$ is not very different from the values given in (31).

Finally the statistical distribution function is:

$$F=\frac{n}{\pi}\left(\frac{m}{2\pi kT}\right)^{3/2}\frac{1}{\left(Cr^2+\frac{1}{C}\right)^2}\times \\ \times e^{-\frac{m}{2kT}\left[\xi^{r^2}+(\xi^z-v)^2+\xi_\varphi^2\right]} \tag{32}$$

where n may be expressed in terms of the total current I and the ion temperature

$$n=\frac{I^2}{4kT}. \tag{31'}$$

The constant C is determined from the initial conditions (for example from the magnitude of the ion density along the symmetry axis).

The authors wish to take this opportunity to express their gratitude once again to their advisors Sherban Titeica and Khorii Kolube for discussion of the work and for the assistance which was graciously offered in its execution.

Appendix. The variables in the equations may be separated under somewhat less stringent working hypotheses: for example, for a distribution of particles with a fixed tangential macroscopic velocity $u_{1,2}$ (tangential velocity $\zeta^\varphi = r\xi^\varphi$).

Under these conditions in B^{12} there is a new term $\left(\zeta^\varphi \frac{\partial F}{\partial \xi^r} - \xi^r \frac{\partial F}{\partial \zeta^\varphi}\right)$, which appears as follows:

$$-\frac{4\pi e (u_1 - u_2)}{r} \int_0^r fr'\, dr' \left(\zeta^\varphi \frac{\partial F}{\partial \xi^r} - \xi^r \frac{\partial F}{\partial r\zeta^\varphi}\right).$$

Whence it follows that the coefficient in $\underline{r}$ is the same as for the term in B_{13}, the variables in the equation are separated, and g_1 in the final form has an exponential factor

$$-\frac{\mu}{2}(\zeta^\varphi - u_1)^2.$$

For f_1 we find the equation

$$\frac{1}{f_1}\frac{\partial f_1}{\partial r} = -\frac{4\pi e^2 [v_1 (v_1 - v_2) + u_1 (u_1 - u_2)]}{kT} \times$$

$$\times \frac{1}{r} \int_0^r f_1 (r') r'\, dr',$$

which after normalization, yields a relation between the current and temperature which differs slightly from that given by I. V. Kurchatov. We assume that this case is not of physical interest (at the outset we introduce an unspecified angular velocity so that the ensemble of particles does not rotate as a unit and frictional forces appear which we have not taken into account in the present equations). These remarks cover all cases in which the solution may be found by separation of variables.

The following class of distribution functions, in which the variables, for the most part, are not separable, but which may be obtained easily, are solutions which describe the rotation with constant angular velocity, of the entire ensemble of ions.

Since this motion leads to the appearance of a field H_z, we transform to a reference system which rotates with the ensemble of particles. In this system H_z vanishes but there is a centrifugal acceleration, which multiplies the radial component of the gradient $\frac{\partial F}{\partial \xi^r}$ in the original equations.

In order to compensate for this term, we introduce the function $F^* = Fe^{\frac{\mu}{2}\psi^2 r^2}$; then a supplementary term appears in $\xi^r \frac{\partial F}{\partial r}$, $\mu \xi^r \psi^2 r$; this cancels the term $\psi^2 r \frac{\partial F}{\partial \xi^r} = -\mu \xi^r \psi^2 r$.

To transform to the fixed coordinate system, it is only necessary to replace ξ^φ with $\xi^\varphi - \psi$ and this leads to the substitution of $e^{\frac{\mu}{2}(r^2\psi^2 - \xi^{\varphi 2} r^2)}$ by $e^{-\frac{\mu}{2}[\xi^{\varphi 2} - 2\xi\psi] r^2}$.

The solution of the problem, taking into account rotation of the system as a whole, will thus include the additional factor $e^{+\mu \xi^\varphi \psi r^2}$.

Authors' Note. After the present paper had been submitted for publication we were kindly informed by Academician I. V. Kurchatov of the results published by W. H. Bennett in his paper "Self-Focusing Streams" [Phys. Rev. 98, 1584 (1955)].

Bennett integrated the nonrelativistic Boltzmann equation, by averaging over velocities, and as a result, obtained the spatial ion distribution.

The results obtained by this author agree with our results which were obtained by a completely different method; our method makes it possible to find, in addition to the result given above, the dependence of distribution function on velocities, which appears to be Maxwellian.

Because the interaction force can be arbitrary, this result is not known a priori, and it is interesting to note that it is obtained by exact calculations.

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EFFECTIVE CROSS SECTIONS FOR FISSION OF U^{233}, U^{235}, Pu^{239} and Pu^{240} BY NEUTRONS WITH ENERGIES FROM 30 KEV TO 5 MEV

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Measurements have been made of the absolute values of the effective fission cross sections in U^{233}, U^{235}, Pu^{239} and Pu^{240}, using as photoneutron sources Sb + Be (~ 30 kev), Na + D_2O (~ 250 kev), Na + Be (~ 900 kev), a source with a simulated fission-neutron spectrum and Po-α-Be. The fission cross sections for 30 kev-neutrons are 3.06 ± 0.16, 2.21 ± 0.12 and 1.79 ± 0.11 barns for U^{233}, U^{235} and Pu^{239}, respectively. As the neutron energy is increased from 30 kev to 250 kev the cross sections in U^{233} and U^{235} fall off by approximately 35% and then remain almost constant while the cross section in Pu^{239} falls off by 12% and then increases. The effective cross sections for fission in Pu^{240} for 900-kev and 5-Mev neutrons is ~ 1.4 barns and the threshold for fission in Pu^{240} lies within the limits 250 and 900 kev.

I. Measurement of the Effective Cross Section for Fission in U^{233}, U^{235} and Pu^{239}

Method of Measurement. To determine the dependence of the effective cross sections for fission on neutron energy, the fission fragments were counted with an ionization chamber with layers of fissile materials. The various neutron sources were placed at the center of a spherical chamber (Fig. 1) and the number of fission fragments was determined.

$$N_f = Q \cdot n \cdot \sigma_f \cdot k_f, \qquad (1)$$

where Q is the strength of the neutron source; n is the total number of nuclei of the fissile isotope in the chamber; σ_f is the effective fission cross section for this isotope; and k_f is a factor which takes into account the experimental geometry.

Since the experimental geometry and the amount of the material in the chamber is the same in all these measurements, the quantities N_f, corrected for the strength of the corresponding source, gives the dependence of the effective fission cross section for a given isotope on the neutron energy. Thus, the variation of σ_f is given by a measurement of the counting rate $N_f(E_n)$ and the ratio of the neutron-source strengths (E_n is the neutron energy).

Experimental Arrangement. The experimental arrangement and the chamber used in these measurements of the relative variation of the fission cross section are shown in Fig. 1.

The fission chamber with Pu^{239} contained about 1.5 mg of material and the fission chambers with U^{233}, U^{235} and U^{238} contained about 20 mg. In all cases the materials were applied electrolytically on aluminum spheres 37 mm in diameter and 0.5 mm thick.

The chambers were filled with a mixture of chemically pure argon and carbon dioxide gas (90% Ar + 10% CO_2) to a pressure of 200 mm Hg. A voltage of + 240 volts was applied to the collector electrode of the ionization chamber.

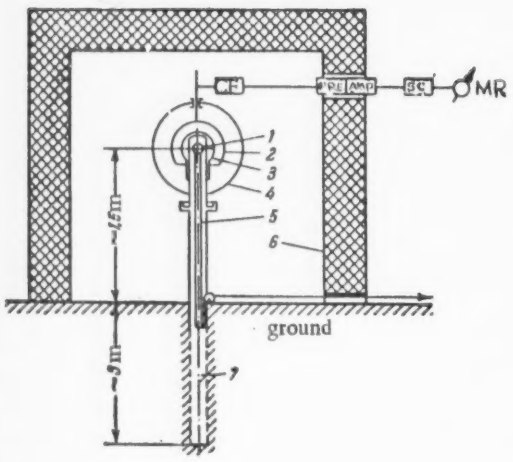

Fig. 1. Diagram of the experimental arrangement. 1) Neutron source; 2) collector electrode 0.3 mm thick; 3) layer of fissile isotope; 4) body of the chamber made from dural 1 mm in thickness; 5) rod for introducing the source remotely; 6) shield made from lead and iron; 7) well for storing the source; CF) cathode follower; PRE) preamplifier; SC)scaling circuit; MR) mechanical register; AMP) amplifier.

The chambers were operated in the electron collection mode. The signals from the chamber were fed to an amplifier through a cathode follower. The amplifier, with negative feedback, had an overall gain of approximately 100,000 and a resolution of about 0.7 μsec.

All the neutron sources used in this work were spherical in shape.. The Po-α-Be source and the simulated fission-neutron source were spheres filled with powder mixtures of Po and Be and Po, B_4C, CaF_2 and $Ca(BF_4)_2$, respectively (the first was 18 mm in diameter, the second 16 mm in diameter). The photoneutron sources were spheres of Be or D_2O, 18 mm in diameter containing a ball of NaF 13 mm in diameter.

In Table 1 is shown a summary of the characteristics of the neutron sources which were used. Values are shown for the energies of photoneutrons from "standard sources" as obtained in the U.S.A. [1] and also for the case of an infinitesimally thin γ-emitter and a neutron emitter (Be or D_2O). Inasmuch as the dimensions of the sources used in the present work were considerably smaller then the dimensions of the "standard sources," the energy of photoneutrons in our work is somewhat higher. The values of the photoneutron energy assumed in the work are shown in the last column.

TABLE 1

Neutron Source Characteristics

Source	Half-life	Angular distribution of neutrons	Energy of photoneutrons from "standard sources"	Energy of photoneutrons for an infinitesimally thin γ-emitter and neutron emitter*	Average neutron energy assumed in present work
Sb + Be	60 days	isotropic	25 kev [2]	30 kev	30 kev (90%) 400 kev (10%)
Na + D_2O	14.8 hours	$1+5\sin^2\theta$ [4]	220 kev [1]	220 kev	250 kev
Na + Be	14.8 hours	$1+0.8\sin^2\theta$ [3]	830 kev [1]	1.00 Mev	900 kev
Simulated fission spectrum	140 days	isotropic	–	–	Mean energy of spectrum ~ 1.9 Mev
Po-α-Be	140 days	isotropic	–	–	Mean energy of spectrum 5 Mev [5]

* The neutron energy was computed from the formula

where E_n and E_γ are the neutron energy and the γ-ray energy in Mev; A is the atomic weight of D_2 or Be; Q is the energy threshold in Mev for the (γ, n)-reaction in a nucleus of mass A; θ is the angle between the direction of the γ-ray and the photoneutron.

We may point out that the line corresponding to 400-kev photoneutrons in the Sb + Be source was obtained on the basis of decay scheme in Sb^{124} and the variation of the cross section for the (γ, n)-reaction in Be [7]. It follows from the decay scheme, that in addition to the main line of γ radiation at 1.71 Mev, yielding neutrons in the beryllium with an energy of approximately 30 kev, Sb^{124} emits γ-rays with an energy of approximately 2.11 Mev and the intensity of these is approximately 22% of the intensity of the γ-rays at 1.71 Mev. In the interaction with beryllium these γ-rays produce neutrons with energies of approximately 400 kev. However, since the effective cross section for the (γ, n)-reaction in Be for these γ-rays is approximately one half as large, the contamination due to neutrons with energies of approximately 400 kev is about 10%.

Control Experiments and Corrections. Since some of the neutron sources have high γ-activity, it was necessary to ensure that the γ-rays were not being registered in the chamber and did not affect the count of fission fragments. In order to check this, a source of γ-rays, Sb and Na, was placed in the chamber, having the same activity as the γ-emitter in the photoneutron sources. Under these conditions, no effect was found at the operating point of the plateau. Furthermore, using a neutron source which did not emit γ-rays (Po-α-Be), the counting rate for fission fragments was plotted as a function of the discriminator setting, and then one of the γ-ray sources was introduced into the chamber and the curve was taken again. It was found that there was no change in the nature of the curve and the counting rate for fission fragments at the operating point remained the same.

In order to reduce effects due to neutrons scattered by the shielding, for which the fission cross section is considerably higher than it is for the primary neutrons, the chamber was covered with cadmium to a thickness of 0.8 mm. However, the effect of neutrons which penetrated the cadmium was still noticeable (2-3%) and it was necessary to measure it. To do this the ionization chambers were placed at a distance of about 25 cm from the neutron source and the effect was measured. Under these conditions, the direct effect of neutrons from the source could be neglected ($\sim$ 0.5%).

Since the chamber walls were approximately 1 mm thick, neutrons from the source are scattered ($\sim$5%) and then interact once again with the isotope layer being tested. Since the cross section for scattering is a function of neutron energy, the effects due to neutron scattering in the walls of the chamber varies from source to source and it was necessary to take this into account. The correction for this effect is no more than 1% of the total variation of the fission cross section.

In deriving the relation given in (1) it was assumed that the experimental geometry was the same for all neutron sources. Actually, because of the finite dimensions of the sources, there may be some change because of differences in neutron angular distributions.

The Po-α-Be source and the source with the simulated fission-neutron emit isotropically over the entire volume of the sphere, while the Sb + Be, Na + D_2O, and Na + Be sources emit neutrons from a spherical layer with different angular distributions; in particular, neutrons from the Sb + Be source have an isotropic distribution while in the sources Na + D_2O and Na + Be the distribution is of the form $a + b \cdot \sin^2\theta$ (compare Table 1). This situation leads to the following: neutrons from different sources pass through the layer of fissile isotope in the ionization chamber at different angles, that is, they interact with different numbers of nuclei. The correction for this effect was introduced on the basis of a geometric calculation and was no greater than 3%.

The anisotropic angular distribution of fission fragments [8, 9, 10] does not appear in the measured results since all fission fragments are detected in the chamber.

Because of the presence in the samples of contamination due to other isotopes (10% U^{238} in the U^{235} sample and 2% Pu^{240} in the Pu^{239} sample) it was necessary to make appropriate corrections. For this purpose supplementary measurements of the values of the effective cross section for fission in U^{238} were made. It was found that the cross section for fission in U^{238}, to an accuracy of $\pm$ 10%, was 0.3 barns for neutrons from the fission spectrum and 0.5 barns for neutrons from the Po-α-Be source; in the other sources this quantity could be neglected. The measurements were made with the ionization chamber shown in Fig. 1. To do this the effective weight of U^{238} in the layer of natural uranium was determined from the number of fission caused by a Sb + Be source of known strength and from the measurement of the U^{235} fission cross section. The correction for the Pu^{240} content was made on the basis of the measurements of σ_f in this isotope, carried out in this work.

The correction for the neutrons with energies of 400 kev in the Sb + Be source was made on the basis of the measured variation of the fission cross section and was no more than 4%.

Results of the Measurement of σ_f. The measurement of the fission cross section were carried out in order and in each measurement the fission fragments were counted alternately with one of the sources enumerated and then with a Sb + Be source for which the neutron fissioncross section was taken to be unity. Comparison of the neutron-source strength with an accuracy of ± 1.5% was possible through the use of the "spherical," "all wave" neutron detector which is described in Section II.

TABLE 2

Relative Values of σ_f in U^{233}, U^{235}, and Pu^{239}

	Isotope	Источники				
		Sb+Be (~30 kev)	$Na+D_2O$ (~250 kev)	Na+Be (~900 kev)	Simulated fission spectrum (~2 Mev)	Po-α-Be (~5 Mev)
Variation of σ_f (experimental data)	U^{233}	1	0.73±2%	0.62±2%	0.63±2%	0.67±1.5%
	U^{235}	1	0.62±1.5%	0.59±1.5%	0.59±3%	0.68±2%
	Pu^{239}	1	0.92±1.5%	1.03±2%	1.06±3%	1.21±1.5%
Corrections for contamination by U^{238} and Pu^{240}	U^{233}	—	—	—	—	—
	U^{235}	—	—	—	−2,5%	−4%
	Pu^{239}	—	—	−1.3%	−1,3%	−1,3%
Corrections for the presence of 400 kev neutrons in the Sb + + Be	U^{233}	—	−3%	−3%	−3%	−3%
	U^{235}	—	−4%	−4%	−4%	−4%
	Pu^{239}	—	−1%	−1%	−1%	−1%
Corrections for anisotropy and the finite size of the sources	U^{233}	—	−3%	−1%	—	—
	U^{235}	—	−3%	−1%	—	—
	Pu^{239}	—	−3%	−1%	—	—
Variation σ_f (corrected)	U^{233}	1	0.69±0.02	0.60±0.02	0.61±0.02	0.64±0.02
	U^{235}	1	0.58±0.01	0.56±0.01	0.55±0.02	0.62±0.02
	Pu^{239}	1	0.88±0.02	1.00±0.03	1.04±0.04	1.17±0.03

In Table 2 are shown the experimental values of the relative magnitudes of σ_f for U^{233}, U^{235}, and Pu^{239} and also the final data obtained by introducing the corrections enumerated above.

II. Measurement of the Absolute Values of σ_f for U^{233}, U^{235}, and Pu^{239}

Method of Measurement. The absolute values of the fission cross sections in U^{233}, U^{235}, and Pu^{239} were measured only for the Sb + Be neutron source. The fission cross sections for other energies were normalized with respect to this value σ_f in accordance with the data of Table 2.

The measurements of the absolute values of the fission cross sections were carried out with thick spherical targets of fissile isotopes. The change in the counting rate of the detector was determined when the neutron source was surrounded by one of these targets. The neutron detector had a uniform sensitivity for neutrons of different energies and was insensitive to elastic and inelastic scattering (an "all wave spherical" detector – Fig. 2). The change in the counting rate was due to the absorption of primary neutrons by nuclei in the target and the production of secondary neutrons as a result of fission.

If a target of fissile isotope is located at a distance from the neutron source such that the direct effect of neutrons at the target may be neglected, the counting rate in the detector is

$$N_2 = Q' k. \qquad (2)$$

When, however, the neutron source is surrounded by a target of fissile isotope, the counting rate of the detector system becomes

$$N_1 = Q \cdot k - Q \cdot k \cdot n\sigma_c + Q \cdot k \cdot n\sigma_c \nu_{eff}. \quad (3)$$

or

$$N_1 = Q \cdot k + Q \cdot kn\sigma_f \frac{\nu(\nu_{eff} - 1)}{\nu_{eff}} \quad (4)$$

Here Q is the strength of the neutron source; k is the detection efficiency for neutrons, which is independent of energy; n is the number of nuclei of fissile isotope per cm^2 of the target; σ_c is the total effective capture cross section; σ_f is the effective fission cross section; ν_{eff} and ν are the mean numbers of neutrons produced in each capture event and each fission event, respectively.

From Relations (2) and (4) we obtain

$$\sigma_f = \frac{N_1 - N_2}{N_2} \cdot \frac{1}{n} \cdot \frac{\nu_{eff}}{\nu(\nu_{eff} - 1)}. \quad (5)$$

To calculate the absolute value of the effective fission cross section σ_f it is necessary to know the values of the quantities ν, ν_{eff} and n with high accuracy.

The uncertainty in $\frac{N_1 - N_2}{N_2}$, caused basically by the statistical error in the measurement of the difference of the counting rates $N_1 - N_2$, was approximately ± 1%. The error in the measurement of the number of nuclei n in the fissile isotopes was insignificant since the target contained approximately 200 grams of material and could be weighed fairly accurately. The value of ν_{eff} has been measured by us earlier [11] with an accuracy of ± 2.5%. The mean number of neutrons ν emitted in one fission event for a primary neutron energy of 30 kev was taken to be the value of ν for fission by thermal neutrons [12, 13] since it is known that as the excitation energy is increased, ν increases approximately linearly [13] and for neutrons with an energy of approximately 2 Mev it is higher by 8-11% as compared with the value for thermal neutrons [14]. The mean square error in the determination of σ_f by the method indicated above was less then ± 5%.

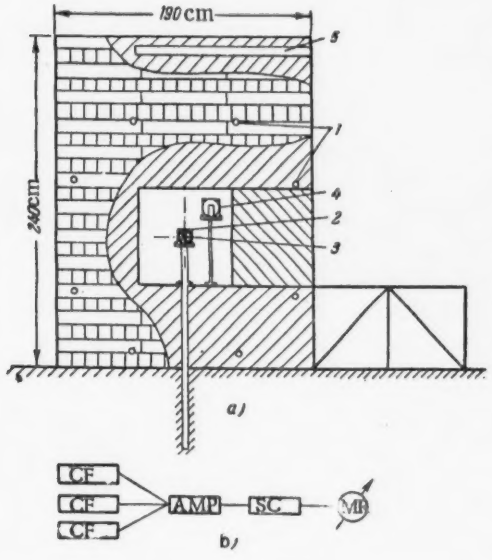

Fig. 2. "All wave spherical" neutron detector. a) Graphite prism: 1) BF_3 counter with cathode follower; 2) filter with target of fissile isotope surrounded by cadmium 0.8 mm in thickness; 3) neutron source; 4) filter with cadmium (without target); 5) channel with BF_3 counters used to compare sources. b) Block diagram of the detection apparatus. C) BF_3 counter; CF) cathode follower; PRE) preamplifier; SC) scaling circuit; MR) mechanical register.

Experimental Arrangement. The neutron detector with uniform sensitivity for neutrons of various energies was made from a graphite prism, shown in Fig. 2, in which there was a system of BF_3 proportional counters. The detector was made insensitive to neutrons scattering ("sphericity") by distributing the counters uniformly about the cavity, while the uniform sensitivity to neutrons of various energies ("all wave property") was achieved by judicious spacing between counters and the boundaries of the cavity. To verify these properties use was made of various neutron sources whose strength could be compared by a method developed in our laboratory by P. E. Spivak and B. G. Erozolimsky. The location of the counters was chosen such that the efficiency for neutrons of different energies (in the range from 30 kev to 5 Mev) was uniform to within ± 2% (taking into account the accuracy and the comparison of the source strength which was ± 1.5%).

The targets of fissile isotopes were hollow spheres with external diameters of 40 mm and internal diameters of 34 mm, with an aperture 21 mm in diameter for introducing the neutron source. The dimensions of the spheres were maintained to within ± 0.05 mm. During the mea-

surements the spheres were covered with cadmium to a thickness of 0.8 mm and enclosed in brass cylindrical absorbers 0.5 mm thick. The isotopic content of the target is shown in Table 3.

Results of the Measurements and Corrections. As has been indicated above, the quantity $\frac{N_1-N_2}{N_2}$ [Eq. (5)] was obtained from two measurements: with the target surrounding the Sb + Be source and with the target separated from the source (by a distance of approximately 20 cm). The presence of the target in the cavity during the second measurement tended to exclude the effect of reflected neutrons in the quantity $\frac{N_1-N_2}{N_2}$. To eliminate effects due to neutron capture by the filter and the cadmium in which the target was placed, a similar filter with cadmium was placed in the cavity; during the measurements the positions of these two were exchanged. In spite of these precautions, in measuring the quantity $\frac{N_1-N_2}{N_2}$ it was still necessary to introduce a correction of ~ 1.2% to take into account the direct effect of neutrons from the source at the target (~ 0.8%) and effects due to reflected neutrons (~ 0.4%) in measuring the counting rate N_2 when the target was far from the source. The measured values of $\frac{N_1-N_2}{N_2}$ with the corrections indicated above and the corrections for neutron capture due to U^{238} contamination in the U^{235} target was found to be as follows: for U^{233}, 0.0861 ± 0.0008; for U^{235}, 0.0438 ± 0.0004; for Pu^{239}, 0.0437 ± ± 0.0004.

TABLE 3

Data on the Fissile-Isotope Targets

Isotope	Weight of alloy in grams	Actual weight of the main isotope in grams	Contamination in percent	Remarks
U^{233}	223.6	220.13	1.35	—
U^{235}	224.9	202.41	U^{238}— 9.83 Others 0.07	
Pu^{239}	190.45	183.3	Pu^{240}— ≤1.8 Ga—1.7 Others — 0.2	Pu^{240} contamination as determined by number of spontaneous fission neutrons

It is still necessary, however, to introduce other corrections in these values to take account of the experimental geometry, the characteristics of the neutron sources, and the behavior of the detection apparatus:

a) Since the Sb + Be source is not a point source the absorption coefficient in the target increases with an increase in the neutron path length in the target. The calculation of this effect can be carried out on the basis of purely geometric considerations and the correction for the targets used in the present work is 6%.

Also, the greater absorption of neutrons in the target leads to multiple scattering of the primary neutrons in the fissile material itself and in the filter which surrounds the target. A calculation of the correction requires the computation of the ratio of the absorption coefficient for multiple scattering in the target and in the filter taking into account the lump effect, and the absorption coefficient in the case of an infinitesimally thin layer without a filter. In doing this it is assumed that neutrons with an energy of 30 kev are scattered isotropically. Since the quantity which is to be determined, the fission cross section, appears in the calculation a successive approximation method must be used. A rapidly converging result is obtained since the uncertainty in the quantity σ_f is a very weak function of the accuracy of the correction. The following values of the corrections were obtained from these calculations: for U^{233} 0.81; U^{235}, 0.79; and Pu^{239}, 0.82.

b) A correction was introduced for the self-multiplication of neutrons, taking into account the interaction of secondary neutrons with the target; this has been calculated by us in an earlier paper [11] and is of the following magnitude: for U^{233}, 1.10; U^{235}, 1.05; and Pu^{239}, 1.10.

In calculating σ_f in accordance with Eq. (5) the values of ν and ν_{eff} multiplied by these correction factors were used.

c) A correction for the presence of neutrons with energies of 400 kev in the Sb + Be source was introduced on the basis of the measurements of the fission cross section and the quantity ν_{eff} which have been measured by us [11] which was ~ +2.5% in U^{233}, ~ +3.5% in U^{235} and ~ −2% in Pu^{239}.

d) Corrections for counting losses in the detection system was determined experimentally by the two-source method and found to be 1.2% for all samples.

TABLE 4

Summary of the Data Used in Determining the Absolute Values of σ_f in U^{233}, U^{235} and Pu^{239} for Neutrons with an Energy of 30 kev

	U^{233}	U^{235}	Pu^{239}
$\frac{N_1-N_2}{N_2}$	0.0861±0.0008	0,0438±0,0004	0,0437±0,0004
ν	2.60±0.07	2.50±0.06	2.9±0.07
ν_{eff}	2.25±0.07	1.86±0.04	2.01±0.05
n	0 0131×10²⁴	0,0122×10²⁴	0,0107×10²⁴
σ_f (in barns)	3.06±0.16	2.21±0.12	1.79±0.11

TABLE 5

Values of the Effective Fission Cross Sections in U^{233}, U^{235} and Pu^{239} (in barns)

Isotope	Sb+Be (~30 kev)	Na+D_2O (~250 kev)	Na+Be (~900 kev)	Simulated fission spectrum (~2 Mev)	Po-α-Be (~5 Mev)
U^{233}	3.06±0.16	2.11±0.13	1.83±0.11	1.86±0.11	1.96±0.12
U^{235}	2.21±0.12	1.28±0.08	1.24±0.08	1.22±0.08	1.37±0.09
Pu^{239}	1.79±0.11	1.58±0.10	1.79±0.12	1.86±0.13	2.10±0.13

In Table 4 are shown the values of $\frac{N_1-N_2}{N_2}$ used in calculating the values of the fission cross section σ_f, and also the absolute values of σ_f for U^{233}, U^{235} and Pu^{239} for neutrons with energies of approximately 30 kev as calculated from Eq. (5). The values of the effective fission cross sections for these isotopes for neutrons of other energies are shown in Table 5.

III. Measurement of the Absolute Values of σ_f in Pu^{240}

A measurement of the absolute values of the effective fission cross section in Pu^{240} for neutrons of various energies was carried out using the method applied in measuring the relative values of σ_f for U^{233}, U^{235} and Pu^{239}. The number of Pu^{240} nuclei in the chamber can be determined from the number of spontaneous fissions. Assuming that in one gram of Pu^{240} there are $1.6 \cdot 10^6$ fissions per hour [15], the effective weight of Pu^{240} was determined (2.0 + 0.2 mg). The contamination due to Pu^{239} in the Pu^{240} layer was determined by comparing the counting rates for identical chambers with a layer of Pu^{240} and with a layer of Pu^{239} in the same thermal neutron flux. The weight of the amount of material in the chamber with the layer of Pu^{239} was determined by counting the fission fragments produced by the action of a Sb + Be neutron source of known strength and from the fission cross sections measured by us for these neutrons.

The absolute values of the strengths of the neutron sources Q was determined with the "all wave" detector by comparison with a standard source whose strength was known with an accuracy of ± 3%.

To determine the neutron flux incident on the layer, account was taken of the relative locations of the various neutron sources with respect to the layer, and of the finite size of the source and the anisotropy in the neutron emission. To reduce to a minimum the background of pulses due to α-particles, in the Pu^{240} chamber, the collector electrode was divided into two halves and the fission fragments were detected by two amplifiers in coincidence.

The results of the measurements of the absolute values of the fission cross sections in Pu^{240} for neutrons of various energy are shown in Table 6.

TABLE 6

Values of the Effective Fission Cross Sections in Pu^{240} (in barns)

Sb + Be (~ 30 kev)	Na + D_2O (~ 250 kev)	Na + Be (~ 900 kev)	Po-α-Be (~ 5 Mev)
0 + 0.1	0 + 0.1	1.3 ± 0.15	1.4 ± 0.15

IV. Discussion of the Results of the Measurements

A comparison of the results obtained in the present work on the effective cross sections for fission in U^{233}, U^{235} and Pu^{239} with the data in the "Atlas of Effective Neutron Cross Sections of the Elements" [16] shows that two are in good agreement.

The results are also in good agreement, within the limits of experimental accuracy, with the data in [17] on U^{233} and U^{235}. However, the data of [17] on Pu^{239} and U^{235} shows essential disagreement both with our data and that published in the "Atlas."

The results shown in Table 6 lead one to the conclusion that the threshold for fission in Pu^{240} lies within the range 250 to 900 kev. It should be noted that the values of the fission cross section in Pu^{240} obtained in the present work are in agreement, within the limits of accuracy of the measurement, with the value (1.6 ± 0.3), given in [18].

In conclusion the authors wish to express their gratitude to P. E. Spivak for help in formulating the problem and a discussion of the results.

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RELATIVE MEASUREMENTS OF THE MEAN NUMBER OF NEUTRONS EMITTED IN FISSION OF U^{233}, U^{235} AND Pu^{239} BY THERMAL NEUTRONS AND BY NEUTRONS CHARACTERISTIC OF A FISSION SPECTRA

V. I. Kalashnikova, V. I. Lebedev, and P. E. Spivak

The ratios of the mean number of neutrons (ν) emitted in the fission of U^{233}, U^{235} and Pu^{239} by thermal neutrons and by neutrons characteristic of a fission spectra have been measured. A method was employed in which the number of fission events was counted simultaneously with the number of coincidences between fragments and fission neutrons. It is found that the quantity ν increases by approximately 10% in all isotopes which were investigated.

INTRODUCTION

The mean number of fast neutrons which is characteristic of one fission event ν for various fissile isotopes varies over rather wide limits (from 2.2 in Pu^{240} to 3.9 in Cf^{252}). Furthermore, in the same isotope the number ν is a strong function of the excitation energy of the fissioning nucleus. It has been shown in various experiments [1, 2], in which a comparison was made between spontaneous fission of Pu^{240} and fission in Pu^{239} induced by thermal neutrons that when the excitation energy of the fissioning nucleus varies from 6.5 Mev, the quantity ν increases by approximately 30%. The corresponding calculations carried out in [2] not only give the right order of magnitude for the quantity ν but also give a rather good prediction of the experimentally observed variation of ν with excitation energy in the Pu^{240} nucleus. According to [2], further increase in the quantity ν with increasing excitation energy of the fissioning nucleus should follow a linear relation, at least up to the point at which the excitation energy becomes large enough to cause the emission of neutrons by the intermediate nucleus before fission.

The experimental data on the quantity ν for fission by fast neutrons of various energies may be used directly for quantitative calculations of the fission process; moreover, with other fission constants (fission cross section, capture cross section, and the mean number of neutrons emitted in one capture event) these are of practical interest in connection with the fast-neutron chain reaction.

The experimental data in [2] taken from a paper by Terrell (Los Alamos) on fission of U^{235} by 700-kev neutrons indicates some increase in the quantity ν in this energy region. The growth of ν in this case is small and amounts to $(2 \pm 2)\%$ as compared with fission by thermal neutrons. The results given in a paper by Fowler (Oak Ridge) for neutron energies of 1 Mev are rather uncertain since the increase in the quantity ν which was observed (15%) is just slightly beyond the limits of the experimental error which was 14%.

The present paper presents the relative measurement of the quantity ν for fission in U^{233}, U^{235}, and Pu^{239} by fast and thermal neutrons. The fast neutrons were obtained from the fission of U^{235} and had a known energy distribution (fission spectrum). The energy of the majority of neutrons was in the limits from 10^5 to $(5\text{-}6) \cdot 10^6$ ev and the mean energy was approximately 2 Mev. The results of an experiment of this type, even if not directly applicable to calculations of a particular fission process are still of general interest in connection with fission and in particular may yield information on the development of a chain reaction for a fission-neutron spectra.

EXPERIMENTAL METHOD

Apparatus. To observe the effect due to an increase in ν accompanying the increasing energy of fission-produced neutrons, use was made of a scheme in which the number of fission events in the sample being investigated was counted simultaneously with the number of coincidences between fragments and fission neutrons; this method has been used earlier by us in [1].

The material being studied was used in quantities varying from 10-30 mg and was deposited on a fine aluminum foil in a layer 0.3-0.5 mg/cm^2 thick. The foil with the layer (target) was placed in an ionization chamber located on the axis of the neutron beam. The fission neutrons were detected in a large cylinder of paraffin in which there were distributed 24 counters filled with BF_3 gas enriched with the B^{10} isotope. The neutron detector surrounded the chamber containing the target. The efficiency for neutron detection, taking into account the solid angle, was approximately 5% for fast neutrons.

The main reading in the detector was caused by fast neutrons from the beam; these entered the detector as a result of scattering by the electrode material and the gas filling the chamber. To reduce the detector loading, first of all, a "beam geometry" was used; the neutron source was placed far from the detector system and the neutron beam was defined by a special system of collimators and shields. In addition, the amount of material in the path of the beam was made as small as possible: the body of the chamber was in the form of a long cylinder with thin ends, separated by boron-paraffin shielding sections and the electrodes were made from aluminum foil 10μ thick. The chamber was filled with argon and a small admixture of carbon dioxide gas to a pressure of 200 mm Hg. Under these conditions the reading due to spurious neutrons in the detector was still ten times greater than the reading due to the fission neutrons when thermal neutrons (with a flux of $\sim (2\text{-}3)\cdot 10^3$ neut./cm^{2}sec) were used and a thousand times greater when fast neutrons (a flux $\sim 5\cdot 10^4$ neut./cm^{2}sec) were used.

Since the lifetime of neutrons in the paraffin block of the detector is very large, the resolving time for coincidences was made $2\cdot 10^{-4}$ sec.

The number of coincidences between fragments and fission neutrons is $n = N\nu\omega\eta$, where N is the number of fragments detected in the chamber. From this it follows that $n/N = \nu\omega\eta$.

The measurements of the quantity $\nu\omega\eta$ were carried out in the material being investigated for fission induced by thermal neutrons and by neutrons characteristic of a fission spectra with a fixed value of the coefficient $\omega\eta$.

Because of the poor coincidence resolving power and the high detector loading due to the spurious neutrons, the random coincidences in the thermal-neutron case were approximately ten percent of the effect being studied and in the work with fast neutrons the random coincidences were comparable with the effect even for a flux $(2\text{-}3)\cdot 10^4$ neut./cm^{2}sec). Thus the main measurements were carried out with flux of fast neutrons no greater than $5\cdot 10^4$ neut./cm^2 sec although the effects due to the true coincidences were small and amounted to several tens per second altogether. Thus, the experiment required extended measurements in the presence of a background which was comparable in magnitude with the effect being studied. For this reason the counting of the effect and the background were carried out simultaneously by means of a special electronic system in which the random-coincidence background was duplicated.

Fast Neutron Beam. The neutron source was the RFT reactor. We had at our disposal a channel in the reactor shield which passed through the center of the graphite reflector, the total thickness of which is 80 cm.

The conversion of thermal neutrons into fast neutrons characteristic of a fission spectra was accomplished by means of a "converter" consisting of 14 grams of U^{235} disposed over an area of 10 cm^2. To obtain a fast neutron flux of the order of $5\cdot 10^4$ neut./cm^{2}sec the converter was placed in a deep channel in a region in which the thermal density was $(2\text{-}3)\cdot 10^4$ neut./cm^3 at a distance of 5 m from the target. At the exit of the channel there was a filter of boron-carbide 3.76 g/cm^2 in thickness.

In a series of preliminary measurements it was shown that in the absence of the converter but with the boron filter at the output of the channel the ionization chamber detected a count of fragments which was 25% of the fragment count with the converter present. Because of this it was necessary to investigate the spectra of the neutron flux which passed through the boron filter when the converter was not present.

On the basis of some simple considerations it may be shown that the fast neutrons which passed through the boron filter when the converter was not present have, on the average, energies in the region of a hundred kev and

higher. In our case the intensity margin was rather high. To reduce the flux intensity a graphite rod 6 cm in diameter and 42 cm long was placed in the assembly gap of the reactor. The scattering cross section in graphite is constant up to a neutron energy of 10^5 ev. However, since the spatial distribution of neutrons pertaining to different groups is different in the assembly gap of the reactor, the graphite rod affects a marked reduction in the number of resonance neutrons and neutrons of intermediate energies. On the other hand, the density of thermal neutrons at the output of the rod is not affected to any great extent. Thus, because of the marked reduction in the graphite scattering cross section in the region of ~1 Mev, the relative number of fast neutrons in the beam increases and, for a rod length of 42 cm, becomes comparable to the number of thermal neutrons. However, it is extremely difficult to draw any definite conclusions as to the spectral composition of these neutrons.

TABLE 1

Target	Flux	Number of fragments	Ratio of counting rates w/o converter and with converter
U^{238}	without converter	6 108	0.250±0.004
	with converter	24 452	
U^{233}	without converter	11 240	0.246±0.003
	with converter	45 715	

The simplest and most sensitive method of comparing the spectral components of the fast-neutron beam from the reactor, which passes through the graphite rod and the boron filter, with the spectrum of fission neutrons from a converter is a comparison of the fission effects produced by these neutrons in materials whose fission cross sections are markedly different functions of neutron energy. Such materials might be U^{233} and U^{238}. In accordance with the foregoing considerations the following experiment was performed. A target of U^{238} was set up in the chamber and the counting rate for fission fragments in the neutron flux behind the boron filter was measured with and without the converter. The counting rate in the latter case was, in fact, 25% of the counting rate with the converter present; this is in good agreement with the corresponding data for U^{233} (Table 1). This result makes it possible to assert, with sufficient accuracy, the spectral components of the fast neutron flux from the reactor, which passes through the graphite rod, correspond to the spectrum of fission neutrons since any difference which exists in the spectra would become apparent because of the sharply different ratio for fission effects in U^{238} and U^{233}.

MEASUREMENTS AND RESULTS

To obtain the ratio of the quantity ν for fission by fast neutrons to the quantity ν_T for fission in a flux of thermal neutrons, the quantity $\nu\omega\eta$ was measured in turn in all three isotopes with the converter in and with the boron filter at the output of the channel and the quantity $\nu_T\omega\eta$ was measured. in the direct beam without the converter. In the latter case the intensity of the thermal neutron flux is reduced to $(2\text{-}3)\cdot 10^3$ neut./cm^{2}sec. The results of the measurements are shown in Table 2.

Two series of measurements were carried out for each isotope. As is apparent from Table 2 the results of both series coincide within the limits of statistical error, which is about 1% in each series.

An estimate of the systematic errors associated with any possible instability in the efficiency of the neutron detector yields a value considerably below 1%.

In analyzing the results for Pu^{239} account was taken of the presence in the target of a small contamination of Pu^{240} which causes a background of spontaneous fissions, amounting to about 2.5% of the number of Pu^{239} fissions caused by fast neutrons. The correction for the background of spontaneous fissions in the calculation of the quantity ν is about 1%.

Corrections for fission effects in Pu^{240} due to fast neutrons were not made since an upper estimate on this quantity shows it is no greater than several tenths of a percent.

Thus a comparison of the mean number of neutrons emitted in fission of U^{233}, U^{235}, and Pu^{239} caused by thermal neutrons and by neutrons characteristic of a fission spectrum shows that the quantity ν increases by approximately 10% in all isotopes which were investigated; however, the dependence of the quantity ν on energy in U^{233} is somewhat weaker than in U^{235} and Pu^{239}.

TABLE 2

Target	Designation	Neutrons	Number of fragments, N	Number of coincidences, n	$\nu\omega\eta$	ν/ν_T	Average for two cases
U^{233}	I	Fast	213 888	28 688	0.1341	1.069	1.075±0.01
		Thermal	938 240	117 664	0.1254		
	II	Fast	215 472	29 236	0.1357	1.080	
		Thermal	760 640	95 568	0.1256		
U^{235}	I	Fast	329 892	44 544	0.1350	1.100	1.10±0.01
		Thermal	1 762 880	216 320	0.1227		
	II	Fast	212 000	28 352	0.1337	1.101	
		Thermal	1 313 720	159 444	0.1214		
Pu^{239}	I	Fast	160 940	25 336	0.1574	1.104	1.11±0.01
		Thermal	942 720	134 428	0.1426		
	II	Fast	148 876	23 368	0.1570	1.114	
		Thermal	678 208	95 544	0.1409		

For a more precise study of the dependence of ν on excitation energy of the fissioning nucleus it would be necessary to follow the variation of ν with energy in fission induced by monochromatic neutrons.

In conclusion the authors wish to thank P. E. Nemirovsky for the interest which he has taken in this work.

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MEASUREMENT OF THE EFFECTIVE CROSS SECTION IN Th^{232} FOR THERMAL NEUTRONS AND THE RESONANCE INTEGRAL FOR NEUTRON ABSORPTION

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The effective cross section in thorium for thermal neutrons (σ_{ther} = 7.31 ± 0.10 barns) and the resonance integral for thorium have been measured in a heavy water reactor. The measurements were made by the activation method. Gold, indium, and uranium were used as comparison standards. The precise value of the effective cross section for indium for thermal neutrons is (σ_{ther} = 162 ± 10 barns) and the resonance integral in indium is (RI = 2340 ± ± 200 barns).

INTRODUCTION

Measurements of the effective capture cross section for thermal neutrons in Th^{232} and the resonance integral for absorption have been carried out at the experimental heavy-water nuclear reactor of the Academy of Sciences, USSR.

Gold, indium and uranium were used as comparison standards.

The measurements were performed in the graphite-reflector of the reactor and also in a channel located between uranium rods in the so-called "well" (the central part of a reactor which is filled with heavy water and contains no uranium rods).

The thorium cross section was determined by the Th^{233} activity, which, according to data given in the literature, has a half-life of 23.3 minutes and emits β particles with an energy of 1.23 Mev. As a result of the β decay, Th^{233} is transformed into the comparatively long-lived (27.4 days) β-active Pa^{233} which emits soft β particles (0.5 Mev). The activation in gold was determined from the β radiation of Au^{198} (half-life 2.7 days, electron energy, 0.963 Mev).

The number of fissions in U^{235} was determined from the β-activity produced by the products of fission of Sr^{89} which emits electrons with an energy of 1.46 Mev (half-life, 53 days).

The activation in indium was measured from the β radiation of In^{116} (half-life, 54 minutes) which emits a complicated electron spectrum with a limiting energy of approximately 1 Mev.

In order to separate the thermal and resonance contributions of the effective cross sections the cadmium ratios were measured in all samples which were investigated. The reproduceability of the cross sections as measured in various points of the reactor serves as a good indication of the reliability of the method.

The number of resonance neutrons at various points of the reactor was also determined by the cadmium ratio in gold.

EXPERIMENTAL PART

Highly diluted solutions of nitrates of the materials being investigated were irradiated in the reactor. Quartz ampules containing 0.3 ml of solution were used. The ampules were placed in various channels of the nuclear reactor. The depths at which the samples were placed was chosen in such a way that the irradiation was carried out in the region of maximum neutron density for each channel,

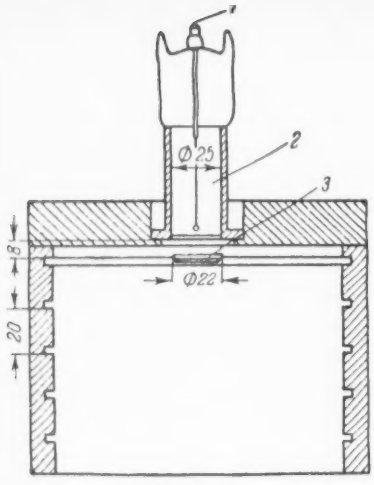

Fig. 1. Arrangement for measuring the activity with an end counter. 1) High voltage; 2) counter; 3) small plate with sample.

The amount of irradiated thorium was less than 60 μg, the amount of gold was 0.75 mg (usually 25 μg was taken), the amount of indium was 8 μ g. and the amount of uranium (natural) was 90 mg. Hence, self-screening in the samples during irradiation could be neglected.

To carry out the measurement of the effective cross sections, the solutions containing thorium and the comparison materials were irradiated simultaneously. Thus the neutron flux was the same for both samples.

To measure the cadmium ratios, the quartz ampules with the materials being tested were placed in a cadmium container 10 mm in diameter and 30 mm high. The wall thickness was 1 mm. Monitors, fabricated from the same material, were placed approximately one and one-half meters from the main ampules (in measuring the cadmium ratio in uranium the monitor was not uranium but indium).

The activity produced by irradiation with and without cadmium was compared with the corresponding activity of the monitor sample.

The irradiation was carried on for 5-10 min. Following irradiation, part of the solution (0.1 ml) was applied to a small plate of stainless steel and allowed to dry. In the uranium case, the strontium was separated out. *

The β -activity measurements were made with a mica-window end counter (mica thickness 0.6 mg/cm^2) using standard geometry (Fig. 1). The geometric counting efficiency was approximately 36%.

Since the energy for the β-particles of all the materials being studied was rather high and approximately the same, corrections for back scattering of electrons in the backing were not introduced.

The Sr^{89} was isolated from the compound (SrC_2O_4) which was present in the amount 6-10 mg (the material was distributed on the plate over an area of ~ 1 cm^2). Under these conditions there is some danger of absorption of β particles in the active layer. However, special measurements indicated that in determining the activity of Sr^{89} the error due to self-absorption was less than 1.5%.

The activities of Th^{233}, Au^{198}, and In^{116} were studied over the course of several (more than five) half-lives. The decay in the activity of Sr^{89} was plotted for approximately one month.

The measured values of the activity were extrapolated to the time corresponding to the end of irradiation. Then corrections were introduced for the decay during the irradiation time.

RESULTS

The cadmium ratios measured for thorium, gold, uranium and indium in various channels of the reactor are shown in Table 1.

TABLE 1

Cadmium Ratios for Thorium, Gold, Uranium and Indium Measured at Different Points in the Reactor

Material	Irradiation site		
	lattice	well	reflector
Th	2.54 ± 0.07	14.4 ± 0.2	45 ± 5
Au	2.38 ± 0.04	9.55 ± 0.2	24 ± 1
U^{235}	22.6 ± 2.0	180 ± 40	500 ± 200
In	2.28 ± 0.10	8.34 ± 0.14	17.4 ± 0.5

The data in Table 1 have been obtained by averaging the results of a number of measurements. The cadmium ratio of uranium in the lattice was measured from the strontium yield. Because this ratio is so high in the well and in the reflector, measurements of the cadmium yield could not be carried out in these channels. Instead, the ratio of the total activity of the fission fragments was measured. To avoid any contribution due to U^{239} which is produced as a result of neutron capture in U^{238}, the measurements in this case were carried out with pure U^{235}.

* For a method of separating out Sr^{89} from the fission fragments see the book: L. E. Glendenin, Natl. Nuclear Energy Ser. Div. IV, Plutonium Project Record; Radiochemical Studies: Fission Products (1951) p. 1460.

The values of the effective cross section in thorium were compared with those for gold, indium, and uranium. The ratio of the cross sections obtained directly from the experiment do not have any simple physical meaning since they are strong functions of the neutrons' spectra. From them, however, the magnitude of the effective cross section for thorium for thermal neutrons and the resonance integral for absorption can be obtained.

In order to make the results more meaningful, we introduce the notion of a mean effective cross section, which, as is clear from the preceding, depends both on the neutron spectrum and on the materisla chosen as a comparison standard. Thus, for example, $\sigma^{Th}_{Ref,In}$ will designate the mean effective cross section for thorium obtained in the reflector for measurements with an indium comparison standard.

In Table 2 are shown the values of the mean effective cross section for thorium.

TABLE 2

Mean Effective Cross Section in Thorium (in barns)

Experimental point \ Comparison material	Au	In	U^{235}
Reflector	7.14	6.25	7.38
Well	7.06	6.19	7.65
Lattice	7.03	6.12	10.62

In calculating the data of Table 2, we have used the following values for the cross sections: 98.6 barns [1, 2] and 145 barns [3] for neutron capture in indium and gold and 590 barns [4] for uranium fission. The Sr^{89} yield in the fission products was assumed to be 4.78% [5].

Using the data shown in Tables 1 and 2, one can calculate the effective cross sections in thorium for thermal neutrons. This quantity, finally, should not depend on the point at which the sample is irradiated nor on the comparision material which is used.

The thorium activity produced by thermal neutrons is equal to the difference in the activity with and without the cadmium. In a similar way, one can find the activity of the comparison material, which is due only to the thermal neutrons.

It is easily shown that the effective cross section in thorium for thermal neutrons, determined, for example, from gold, can be found from the formula

$$\sigma^{Th}_{ther\ Au} = \sigma^{Th}_{M,\,Au}\,\frac{R_M(Au)}{R_M(Th)}\cdot\frac{R_M(Th)-1}{R_M(Au)-1}\,. \qquad (1)$$

In Eq. (1) $R_M(Au)$ and $R_M(Th)$ designate the cadmium ratios for gold and thorium measured at a point M, while $\sigma^{Th}_{M,Au}$ is the mean effective cross section for thorium at the point M measured with gold as a comparison standard. The quantities which appear in Eq. (1) are given in Tables 1 and 2.

The values of the effective cross section in thorium for thermal neutrons calculated from Eq. (1) are given in Table 3.

TABLE 3

Effective Cross Section in Thorium for Thermal Neutrons Measured at Various Points in the Reactor with Different Comparison Materials (in barns)

Experimental point \ Comparison material	Au	In	U^{235}
Reflector	7.29	6.49	7.24
Well	7.33	6.54	7.17
Lattice	7.31	6.61	6.75

We now consider the results shown in Table 3. The cross sections determined from gold are found to be in excellent agreement with each other. The cross sections measured in indium, differ between themselves by 2% and are noticeably lower than the cross sections measured with gold. The fact that, in general, the cross sections measured in indium are lower is apparently connected with the uncertainty in the value of its cross section which was used (the cross section for indium, 145 barns was measured with an error of ± 15 barns). In order to bring the present results into agreement with each other, one must assume that the effective cross section in In^{115} is 162 ± 10 barns. The spread in the cross sections in thorium, determined with an indium standard in different channels, is probably due to impurities which

were contained in the indium which was used: we have found systematic differences (within the limits from 55 to 58 min) in the values of the half-life.

The largest spread in the values were obtained for the measurements of the thorium cross section made with the uranium comparison standard. The values of this cross section obtained with irradiation in the reflector and in the well, are in satisfactory agreement with each other and with the cross section measured in gold. The value of the cross section obtained in the lattice is considerably lower. It should be kept in mind, however, that this value differs from the other cross sections by 6% although it was obtained by scaling the high mean effective value 10.62 (cf. Table 2).

Thus, it would seem that the best values are those obtained with the use of the gold standard. Taking into account the uncertainty in the weight of the gold and thorium samples the effective cross section in thorium for thermal neutrons is 7.31 ± 0.10 barns. This value agrees with the value obtained in [6].

The resonance integral for absorption in thorium is calculated from the expression

$$RI(\mathrm{Th}) = RI(\mathrm{Au})\,\frac{\sigma_{\mathrm{ther\ Th}}}{\sigma_{\mathrm{ther\ Au}}}\cdot\frac{R_{\mathrm{Au}}-1}{R_{\mathrm{Th}}-1} \qquad (2)$$

Assuming that the resonance integral in gold $\left(\int \sigma(E)\frac{dE}{E}\right)_{\mathrm{Au}}$ has a value 1326 ± 15 barns [7], we obtain the following value for the resonance integral in thorium (the contribution to the cross section which is proportional to 1/v is not considered):

(88 ± 5) barns in the lattice,
(63 ± 2) barns in the well,
(59 ± 6) barns in the reflector.

The differences in the values of the resonance integral in the lattice, in the well, and in the reflector are to be expected since the neutron resonance spectrum in these different places is of different form: it is almost a Fermi spectrum in the lattice but departs markedly from a Fermi spectrum in the well and in the reflector.

It is unfortunate that the experimental geometry (Fig. 2) was such that even in the lattice a Fermi spectrum could not be obtained. Thus, it cannot be stated with certainty that the value of the resonance integral 88 barns is obtained in a spectrum $(nv)_E\,dE \sim \frac{dE}{E}$.

The resonance integral for indium in the lattice, was calculated in a similar fashion and found to be 2340 ± ± 200 barns.

Assuming that the neutron spectrum in the lattice may be divided into two components, Maxwellian and Fermi, it is possible to calculate the ratio of these components.

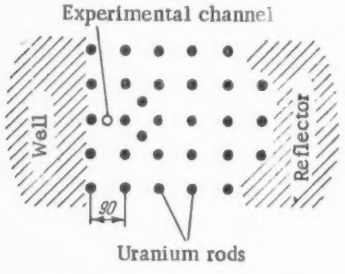

Fig. 2. Diagram showing the arrangement of the experimental channel in the reactor lattice.

The thermal neutron flux can be characterized by the quantity nv_0 where n is the neutron density and v_0 is the most probable velocity for thermal neutrons at 20° C (v_0 = 2200 m/sec). Assuming that the flux of resonance neutrons in the lattice is characterized by a Fermi distribution, we find

$$(nv)_E\,dE = C\,\frac{dE}{E}. \qquad (3)$$

The constant C has the dimensions of flux and is usually called the flux of resonance neutrons.

In the usual neutron slowing-down theory

$$C = \frac{q}{\xi N \sigma_s}, \qquad (4)$$

where q is the slowing-down density; ξ is the average logarithmic energy loss for the neutrons; N is the number of atoms per cm^3; σ_s is the scattering cross section.

As is well known,

$$\frac{nv_0}{C} = (R_{Cd} - 1) \frac{\int \sigma_a \frac{dE}{E}}{\sigma_0} . \qquad (5)$$

Substituting in Eq. (5) for gold $\left(\int \sigma \frac{dE}{E} \right)_{Au} = 1326$ barns [7]; σ_0 = 98.6 barns [1, 2] and R_{Cd} = 2.38 (cf. Table 2), we find $\frac{nv_0}{C}$ = 18.5.

Note. When the present paper was in press, a paper by Macklin and Pomerance appeared [8] in which the resonance integral in thorium was also measured. The authors assign a value of (67 ± 5 barns). The experiment was performed by activating thorium in a neutron beam. The comparison standard was gold and the resonance integral in this material was taken to be 1513 barns (while we assumed a value of 1326 barns).

In order to compare the present results with those of Macklin and Pomerance, the $\frac{1}{v}$ contribution to the cross section should be taken into account and the data should be recomputed using a gold cross section of 1513 barns. This procedure yields:

(96 ± 6) barns in the lattice,
(68 ± 3) barns in the well,
(64 ± 7) barns in the reflector.

The value (67 ± 5) barns was obtained by Macklin and Pomerance in a beam in which the cadmium ratio for gold was 2.75. In our case the cadmium ratio for gold was 2.38 in the lattice and 9.6 in the well. Thus, the experimental conditions in the work of Macklin and Pomerance lie between our experimental conditions as observed in the lattice and the well although they are closer to the former. Their result is close to the result we obtained in the well. Since, however, the cadmium ratio does not give a complete characteristic of the spectrum, which in both cases may differ noticeably from a Fermi distribution, it is not possible to assign a cause for the discrepancy between the results.

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NUCLEAR FISSION IN HEAVY ELEMENTS BY HIGH-ENERGY PARTICLES

A. K. Lavrukhina and L. D. Krasavina

The results of a radiochemical investigation of nuclear fission in uranium, thorium, and bismuth by protons with an energy of 680 Mev are presented. Using an interpolation method a complete chart of the fission residue products is obtained. It is noted that there is a predominance in the production of nuclei with excess neutrons (58-64%); it is also shown that isotopes with maximum yield lie mainly in the neutron-excess region. The probability for symmetric fission is largest in bismuth. The cross sections for fission in uranium and thorium are 55-60% of the geometric cross section; in bismuth it is 5%. The charge distribution of fragments in fission induced by high energy protons is constant and independent of the mass number of the fission fragments and the atomic number of the fissioning nucleus. An analysis of the main features of the fission process seems to indicate that fission in uranium and thorium is due to a combined barrier-emission mechanism.

INTRODUCTION

The interaction of high-energy particles (~ 100-700 Mev) with complex nuclei takes place in two steps:

a) The ejection of fast particles at the moment of the collision between the bombarding particle and the nucleus;

b) The subsequent emission of slow particles by evaporation from the excited nucleus.

As a result of these processes a certain number of nucleons are removed from the original nucleus and new nuclei are formed – disintegration products which occupy a wide region of mass numbers starting from those which border on the bombarding element and extending far from it. In the second stage fission of the nuclei of the heavy elements may also take place.

Numerous studies, in which physical methods have been employed, have furnished the magnitudes of the fission cross section for a whole series of nuclei [1, 2, 3] and have furnished data with regard to the angular and energy distributions of the fission fragments and the excitation energy of the fissioning nuclei [4-7].

A radiochemical method, on the other hand, makes it possible to establish the distribution of yields of radioactive fission fragments, which have half-lives convenient for measurement, by mass number [8-15] and also to obtain information on the nautre of the radioactive fission fragments themselves. It is found that in fission induced by fast particles isotopes are produced which are characterized by both a neutron excess and a neutron deficiency. However, the absence of data on yields of stable and short-lived radioactive isotopes means that it is impossible to give a comprehensive description of the fission products or to determine the total fission cross section in different nuclei or to examine the mechanism associated with this process in greater detail.

In this work an interpolation method has been used to make an estimate of the yields of stable and unidentified radioactive isotopes which are produced in the fission of bismuth, thorium, and uranium induced by 480-Mev protons. This procedure makes it possible to obtain a complete picture of the fission products of these nuclei and to explain certain details of the fission phenomena.

Complete Chart of the Products of Fission in Uranium, Thorium and Bismuth by 480 Mev Protons

In order to develop a comprehensive picture of the fission products in uranium, thorium, bismuth induced by 480-Mev protons the yields of stable and unidentified radioactive isotopes were determined from the radiochemical data published in [15]. Using an isotope chart with coordinates N–Z a plot was made of the radioisotopes, as identified by fission products, and the yields were indicated [16]. The yield values, corresponding to the isotopes Eu^{152}, Eu^{156}, Tb^{161} for uranium and Eu^{152}, Eu^{156} and Gd^{159} for thorium are taken from [17].

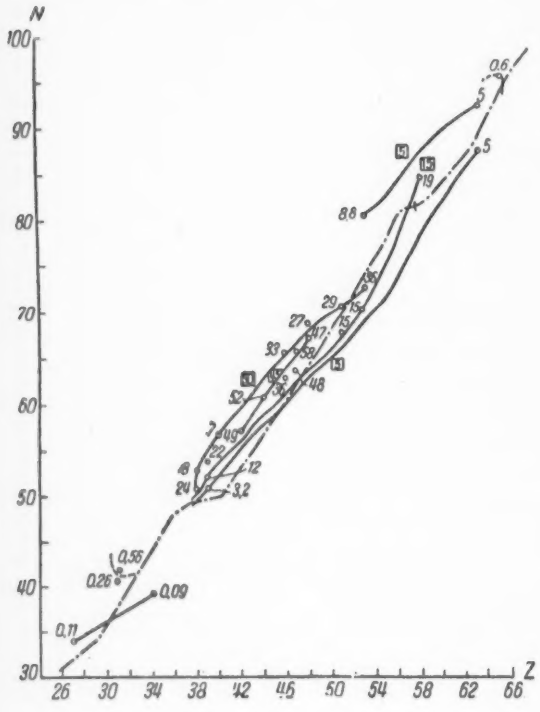

Fig. 1. Radioisotope yields for uranium fission by 480-Mev protons.

As an example, in Fig. 1 is shown a chart of the isotopes produced in uranium fission. Isotopes with the same yield are connected by solid lines while the dotted line indicates the line of nuclear stability, which corresponds to stable isotopes with maximum content of the natural mixture. It is apparent from the configuration of these lines that in elements with $Z \leq 46$, with the exception of Se^{73}, only isotopes with excess neutrons are produced; for elements with $Z > 46$ isotopes with neutron deficiencies are found. This same pattern was observed in thorium; in bismuth, isotopes with neutron deficiency are observed even for elements with $Z > 29$.

In all three cases the line of maximim isotopic yield lies in the region characteized by isotopes with excess neutrons.

Using the lines on the isotope charts it was found possible to interpolate yields* for a large number of stable and unidentified radioactive isotopes. The interpolation accuracy is 50%. Using the experimental data and interpolation, curves were plotted of the distribution of yields for various elements in terms of mass number. These curves have the same form as the curves plotted for the uranium products (Fig. 2). The characteristic bell-shaped form of these curves made it possible to extrapolate to remote regions (for which there were no data on yields) by comparison with the regions

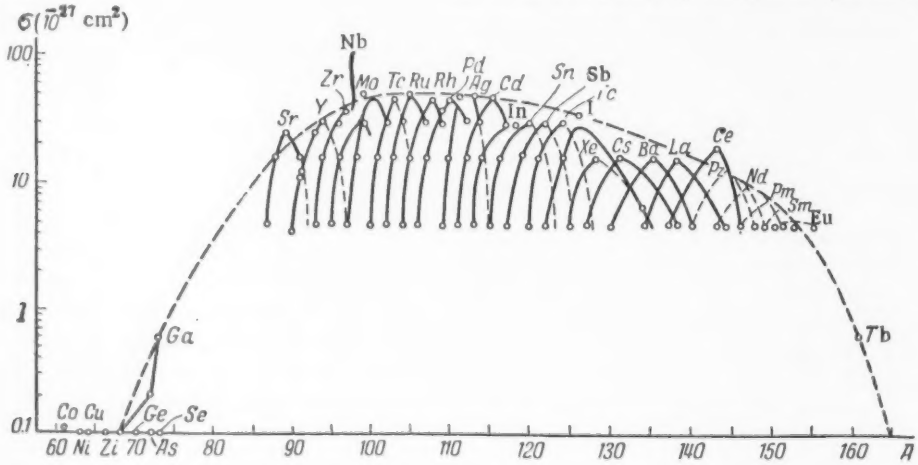

Fig. 2. Distribution curves for yields of isotopes of various elements for uranium fission by 480-Mev protons by mass number.

* By yield is meant the cross section for the production of a given isotope (σ).

associated with neighboring elements. This extrapolation is indicated by the dashes. Using the curve which was obtained it was found possible to make estimates, with the accuracy indicated above, of the yield of still other elements. A line was drawn connecting the peaks of all the curves and falling off on each side below the values of the yields for Ga^{73} and Tb^{161} in the uranium case and Ga^{73} and Gd^{159} in the thorium case. From these curves a rough estimate can be made of the isotopic yields in rubidium, krypton, bromine, selenium, arsenic, praseodymium, neodymium, promethium, samarium and europium.

TABLE 1

	Nucleus	U^{233}	Th^{232}	Bi^{209}
1	Isotope contribution (in percent of σ_{fis}):			
	stable	21	31	28
	with neutron deficiency	11	5	12
	with neutron excess	58	64	60
2	Region of nuclei with maximum yield . . .	Sr^{89}, Y^{94}, $Zr^{96, 97}$, Nb^{98}, Mo^{99-101}, Tc^{103}, Ru^{103}, Rh^{108}, Pd^{110}, $Ag^{111-113}$, $Cd^{115, 116}$, In^{118}, Sn^{120}, Sb^{121}, Te^{123}, I^{126}, $Xe^{127, 128}$, Cs^{131}, Ba^{135}, La^{137}, Ce^{143}, Pr^{144}, $Nd^{146, 147}$, Pm^{149}, Sm^{151}, Eu^{154}	Se^{83}, Br^{84}, Kr^{87}, Rb^{89}, Sr^{91}, Y^{93}, Zr^{95}, Nb^{97}, Mo^{99}, Tc^{101}, Ru^{104}, Rh^{106}, Pd^{108}, Ag^{111}, Cd^{115}, In^{118}, Sn^{120}, Sb^{123}, Te^{126}, I^{129}, Xe^{132}, Cs^{135}, $Ba^{137, 138}$, La^{140}, Ce^{141}, Pr^{143}, $Nd^{146, 147}$, Pm^{149}, Sm^{150}, Eu^{152}	Ga^{72}, Ge^{75}, As^{77}, Se^{78}, Br^{80}, Kr^{82}, Rb^{85}, Sr^{92}, Y^{93}, Zr^{96}, Nb^{97}, Mo^{99}, Tc^{102}, Ru^{105}, Rh^{107}, Pd^{112}, Ag^{111}, Cd^{115}, In^{117}, Sn^{120}, $Sb^{121, 123}$, Te^{124}, Ba^{129}
3	Total fission cross section σ_{fis} ($\times 10^{-24}$ cm^2)	1.65	1.6	0.1
4	Probability for symmetric fission (in percent of σ_{fis})	32	27	45

Using this interpolation method it was possible to estimate the yields for a large number of isotopes. Thus, in the fission products of uranium the yields of 240 isotopes were estimated (excluding those obtained from the experimental data) in thorium 244, and in bismuth 252. It should be noted that only 8-10% of the indicated total number of isotopes can be produced in a long decay chain (up to 4 links). In the other isotopes the earlier isobars in the chain have a comparatively large decay period (several hours and higher) and thus the yield of these isotopes could not be increased by more than a factor of two under the present experimental conditions.

The distribution curves of isotopic yields for the different elements, as plotted by mass number (for example, Fig. 2), gives a more complete picture of fission products in uranium, thorium and bismuth due to 480-Mev protons and makes it possible to estimate the fraction of the stable isotopes as well as the isotopes with neutron deficiencies and excesses, the region of nuclei with maximum yield, the total cross section for fission and the probabilities for symmetric fission and fission which is almost symmetric.

Under this latter term is to be understood fission resulting in nuclei with $Z_c - Z \leq \pm 3$ (Z_c corresponds to a nucleus produced in symmetric fission). The data pertaining to these quantities are presented in Table 1.

The following conclusions may be drawn from these data.

1. In fission of uranium, thorium and bismuth induced by protons with energies of 480 Mev, there is a preponderance of isotopes with excess neutrons; the fraction of isotopes with neutron deficiencies is insignificant at this proton energy.

2. The isotopes characterized by maximum yield lie in the isotope region with excess neutrons, while the heavy fission fragments lie in the region of nuclear stability.

3. The total cross sections for fission in uranium and thorium are large and correspond respectively to 55% and 60% of the geometric cross sections for these nuclei. The cross section for fission in bismuth is small and is 5% of the geometric cross section.

4. The probability for symmetric fission and fission which is almost symmetric is largest in the bismuth case (45% of the total fission cross section), while for uranium and thorium it is somewhat smaller. This result is in agreement with the data of [4] with respect to the distribution of the range ratios for fission fragments in bismuth and uranium for various excitation energies.

Charge Distribution of Fission Fragments

One of the important characteristics of fission is the charge distribution of the fission fragments.

Information concerning the charge distribution of the fission fragments can be obtained from a radiochemical analysis of the yields of the primary fission fragments.

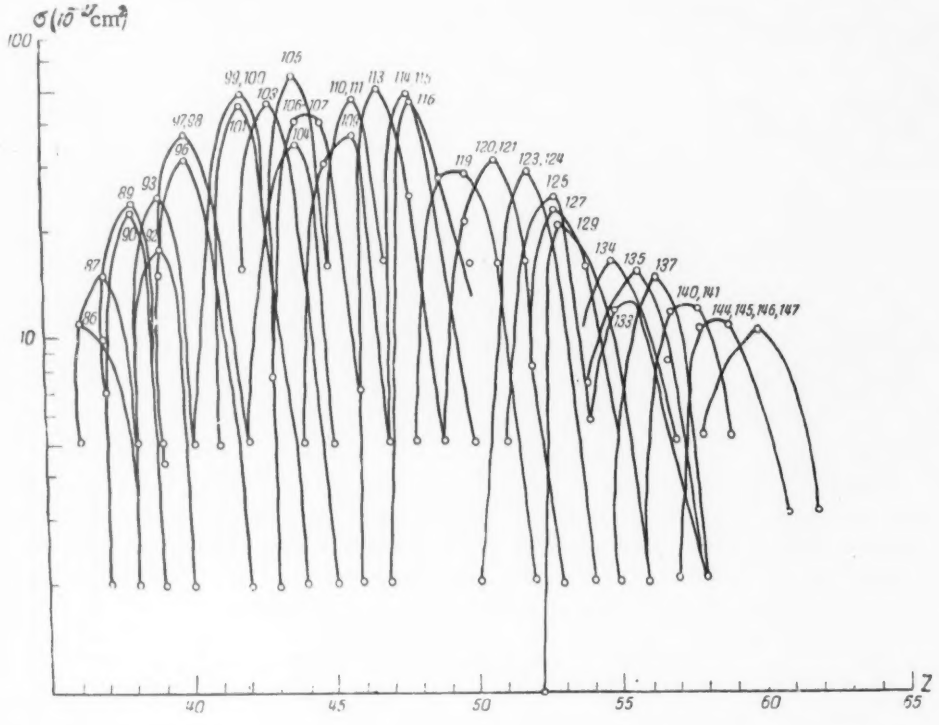

Fig. 3. Nuclear charge distribution curves for isobars of different mass number in uranium fission by 480-Mev protons.

In view of the fact that the experimental and interpolated magnitudes of the yield products in fission of uranium, thorium and bismuth by 480-Mev protons are 90% independent, there were used to establish the charge distribution of the fission fragments for these nuclei. For this purpose curves were plotted showing the distribution of yields of different isobars, produced in the fission of uranium, as a function of atomic number. As is apparent from Fig. 3, these curves have a typical bell-shaped form for all isobars in the region of mass number from 86 to 145. The width of the charge distribution curves is 2-3 mass-number units. Similar curves were obtained for fission fragments for thorium and bismuth.

To determine the quantity Z_p – the most probable charge for a given mass number – using the isotope chart plotted in terms of N, Z, a median line was drawn for the curves corresponding to isotopes with maximum yield. The intersection points of this line with the lines drawn through the isobaric nuclei correspond to Z_p for the different isobars.

To determine the location of Z_p with respect to the line of nuclear stability, use was made of the magnitude of the most probable charge for the stable nuclei (Z_A) for these same isobars [18]. The quantities Z_A and

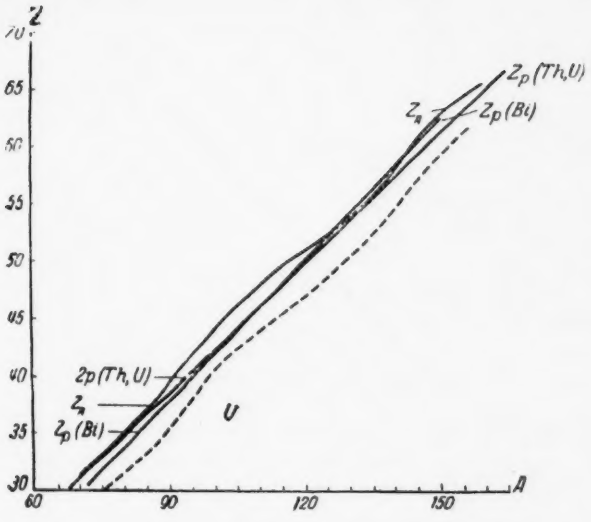

Fig. 4. The dependence of Z_A and Z_p on mass number for fission of uranium, thorium and bismuth by 480-Mev protons (solid curves) and U^{235} by thermal neutrons (dashed curve).

Z_p as functions of A are shown in Fig. 4; it follows from these curves that the most probable charge values in fission of uranium, thorium and bismuth by 480-Mev protons are located close to the line of nuclear stability. In this regard fission induced by fast protons is different from fission of U^{235} due to thermal neutrons since the curve of Z_p as a function of A in the latter case is considerably below the curve for Z_A in the region of nuclei with large neutron excesses (Fig. 4, dotted line). However, in fission of heavy nuclei, Z_p is still located in the region of nuclei with excess neutrons, even for energies of the bombarding particles up to 500 Mev.

The charge distribution curves for fission in uranium and bismuth by 480-Mev protons are shown in Fig. 5. In general, the nature of the charge distribution curves for fission in these nuclei is the same, with the exception that the curve in the bismuth case is displaced by ~ 0.5 atomic-number units with respect to the uranium curve; this may be due to the poor accuracy in the determination of Z_p. The fractional yield (the fraction of the total yield for a given mass number) of the most probable charge is ~ 0.5, and ~ 0.01 for the least probable. The variation in the magnitude of the fractional yield in fission by high-energy particles is considerably smaller (from 0.5 to 0.01) than for fission by thermal neutrons (from 0.4 to 10^{-5}) [19].

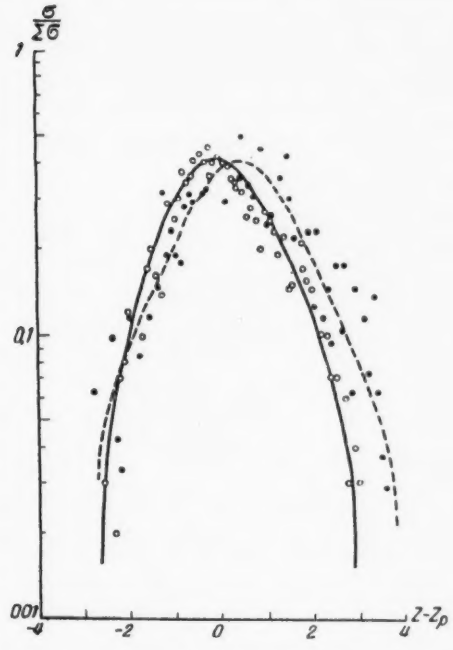

Fig. 5. Charge distribution curves for uranium fission (solid curve) and bismuth fission (dashed curve) by 480-Mev protons.

From what has been indicated above it follows that fission induced by high-energy particles is characterized by a fixed charge distribution regardless of the mass number of the fission fragments and the atomic number of the fissioning nucleus. This conclusion is also supported by the fact that the magnitudes of Z_p in accordance with the hypothesis of an equal charge distribution, according to which the ratios $\frac{A-Z}{Z}\left(\text{or } \frac{A}{Z}\right)$ are the same for the most probable fission fragment and the fissioning nucleus (given in Table 2, line 6) are in good agreement with the values of Z_p determined by the experimental and interpolated data. This is apparent from Figs. 6 and 7 in which Z_p is shown as a function of A for fission in thorium and bismuth.

In the fission of U^{235} by slow neutrons, in contrast with fission by fast particles, there is not an equal distribution of charge and the most probable charge distribution is characterized by an equal departure of the charge of the primary fission fragments from the charge which corresponds to the final stable state for a given mass number of the fragment [19].

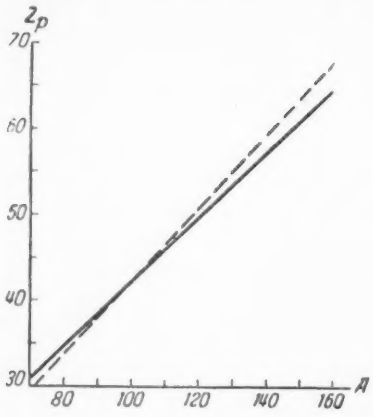

Fig. 6. The dependence of Z_p on A for thorium fission by 480-Mev protons. Solid line) According to the experimental and interpolated data; dashed line) according to data calculated on the basis of an equal charge distribution.

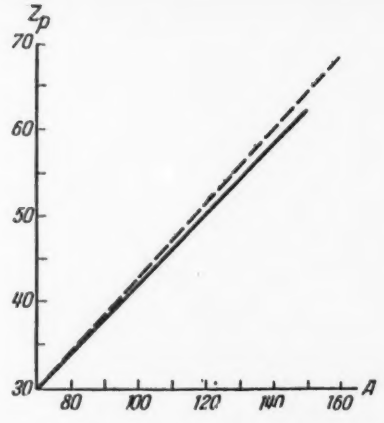

Fig. 7. The dependence of Z_p on A for bismuth fission by 480-Mev protons. Solid line) According to the experimental and interpolated data; dashed line) according to data calculated on the basis of an equal charge distribution.

Mechanism for Fission in Uranium, Thorium and Bismuth Induced by High-Energy Particles

The mechanism by which fission is induced in nuclei by fast particles has been discussed in many papers ([2, 4, 11, 13, 16, 20-23], etc.). At the present time we may assume that two definite mechansims have been established for fission in a nucleus excited as a result of an intranuclear cascade:

1. The nucleus is divided into highly excited states; in this case excited fragments are produced which subsequently evaporate neutrons and, to a lesser degree, protons (barrier or high-temperature fission).

2. Prior to fission the nucleus evaporates a large number of neutrons (emissive fission). This mechanism was first proposed by Goeckermann and Perlman [13] in explaining the fission of bismuth by neutrons with an energy of 190 Mev. All available data, obtained either by radiochemical methods or by various physical methods seem to indicate that fission in the region of Z from ~ 83 to ~ 73 is a result of an emission mechanism.

Up to the present time, however, there is no single idea to explain fission in heavy elements (uranium and thorium). Thus, in [2, 4, 16 20] an argument for an emission barrier mechanism in uranium fission was presented; in [11, 22, 23] the emission character of fission in these nuclei was emphasized. It should be noted, however, that the conclusion as to the emission character or uranium fission is based on considerations which derive from evaporation theory. Inasmuch as different versions of the theory of evaporations [24, 25] give different values for the number of evaporated particles, these calculations cannot uniquely interpret the experimental data. Thus, up to the present time the question of whether fission can interrupt the evaporation process caused by an intranuclear cascade in the uranium nucleus or whether fission occurs after the excitation of the nucleus has been dissipated in the evaporation of different particles has remained open question.

The information acquired in the present work on the magnitudes of the total fission cross section in various nuclei, the relation between the cross sections for spallation and fission, the yields and the values of the ratio $\frac{A-Z}{Z}$ for a large number of fission fragments makes it possible to draw certain conclusions as to the fission mechanism in uranium and thorium nuclei.

Using the magnitudes of the ratio $\frac{A-Z}{Z}$ in almost all fission products the number of neutrons which can be evaporated from the excited nuclei before fission was determined for these fission products. In doing this it was assumed that the ratio $\frac{A-Z}{Z}$ was the same in the fission fragments and the fissioning nucleus and that two

fast neutrons (including the bombarding proton) and two fast neutrons are emitted as a result of the intranuclear cascade. Taking account of the magnitude of the yield for different fission products, the probability for evaporation of neutrons and the average number of neutrons evaporated before fission in uranium, thorium, and bismuth was calculated. The data on these quantities are presented in Table 2.

TABLE 2

	Bombarded nuclei		
	U^{238}	Th^{232}	Bi^{209}
1. Magnitude of total cross section ($\times 10^{-24}$ cm^2)	1.65	1.6	0.1
2. Ratio $\frac{\sigma fis.}{\sigma spal.}$	~ 1	~ 1	0.1-0.2
3. σ for fission accompanied by the evaporation of (11-15) neutrons ($\times 10^{-24}$ cm^2)	0.35	0.6	0.037
4. σ for fission accompanied by the evaporation of (1-5) neutrons ($\times 10^{-24}$ cm^2)	0.11	0.03	0.007
5. Average number of neutrons evaporated from the excited nuclei	17	19	13
6. Most probable fissioning nucleus for emission fission	Pa^{218}	Ac^{210}	Pb^{193}
7. A for the most probable fissioning nuclei taken from the curve showing the dependence of σ on A (Fig. 8)	214-234	–	194-196

It is apparent from the data of Table 2 that there is a considerable difference in the cross sections for fission in uranium and thorium on the one hand as compared with bismuth on the other. This also applies to the magnitude of the ratio $\frac{\sigma fis.}{\sigma spall.}$. This situation indicates that the probabilities for fission and spallation are almost equal in uranium and thorium while in bismuth the spallation process has a considerably higher probability (by a factor of ~ 10). It is particularly noteworthy that the cross section for fission in uranium and thorium, in which it is possible that 11-15 neutrons may be evaporated by the excited nucleus prior to fission, is 10-15 times greater than the fission cross section in bismuth. This fact would seem to indicate that the fission mechanism is a different one in these two nuclei. As is well known, the cross section for evaporation of an equal number of neutrons from these nuclei is the same [16], hence the cross section for fission should be the same if fission takes place as a result of an emission mechanism.

The cross section for fission in the uranium nucleus, which is accompanied by the evaporation of from 1 to 5 neutrons, is comparatively large. This would seem to indicate that fission in this element can occur, with rather large probability, after the evaporation of a small number of neutrons.

A comparison of the mass numbers for the most probable fissioning nuclei, assuming the same emissive nature for fission in uranium and bismuth, with the curve showing the dependence of the total yield of isobars on these mass numbers (Fig. 8), indicates that these quantities are the same in bismuth but are markedly different in uranium.

From the dependence of the ratio $\frac{A-Z}{Z}$ for nuclei with the most probable Z_p on their mass number, it is also possible to draw some conclusion as to the fission mechanism. Actually, if fission occurs as a result of an emission mechanism, this ratio should be the same for heavy and light fragments. If, however, neutrons are emitted from the excited fission fragments, then it is not very likely that the magnitude of this ratio will be the same for light and heavy fragments. The different character in the dependence of $\frac{A-Z}{Z}$ for the most probable fission fragments in uranium and bismuth (Fig. 9) clearly indicates a difference in the fission mechanism. This is also indicated by the difference between the direct dependence of Z_p on A plotted from the experimental and interpolated data and the data calculated under the assumption that the ratio $\frac{A-Z}{Z}$ is the same for the fissioning

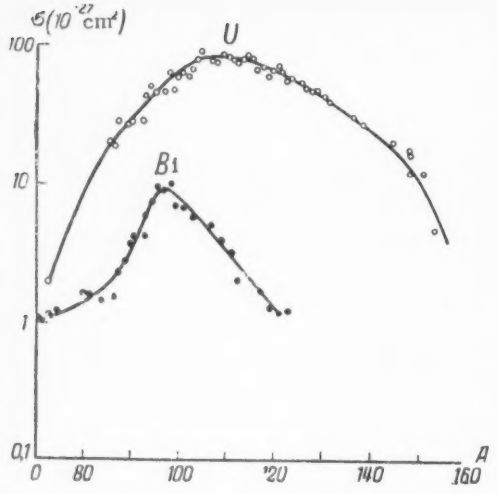

Fig. 8. Total yields of various isobars in uranium fission (–o–) and bismuth fission (–o–) by 480 Mev protons as a function of mass number.

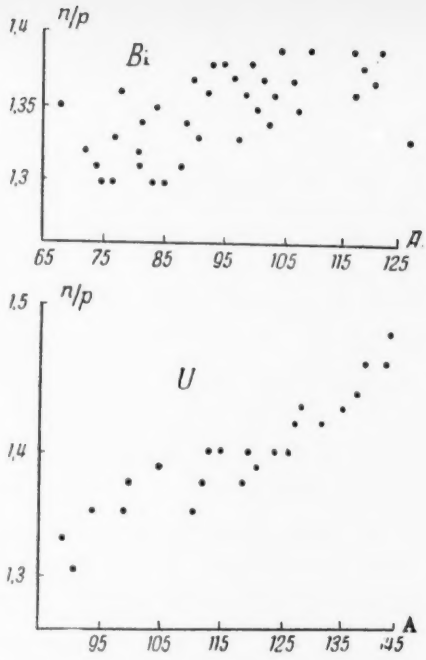

Fig. 9. The quantity $\frac{A-Z}{Z}$ for nuclei with the most probable charge produced in the fission of uranium and bismuth by 480 Mev protons.

nucleus and the fission fragments. This difference is larger in thorium (Fig. 6) than in bismuth (Fig. 7).

Everything that has been pointed out above seems to indicate that fission in uranium and thorium cannot be explained by a purely emissive mechanism. The data of the present work indicates that fission, in this case, interrupts the evaporation of neutrons at some stage in the development of the excited nucleus, and the excited fragments in turn themselves evaporate neutrons. Consequently, the fission of uranium and thorium nuclei by high-energy particles occurs as a result of a combined barrier-emission mechanism.

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1-1/2 METER FIXED-FREQUENCY CYCLOTRON

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A brief description is given of a 1-1/2 meter cyclotron. Questions connected with the acceleration of ions in the central part of the cyclotron are considered. The most important points for the correction of magnetic field are indicated. The deflection and focusing of the accelerated ion beam are considered. Data on the energy and flux of accelerated particles are presented.

INTRODUCTION

The design of this cyclotron was initiated in 1945. At the same time design studies were started on the building in which the machine and laboratory facilities were to be housed. Construction was completed in 1946 and in 1947 a deuteron beam was produced and extracted from the chamber.

To provide radiation shielding for personnel and instruments the cyclotron is enclosed by a water shield 1 m in thickness. The cyclotron is operated from a central control station which is located behind the shield.

The presence of intense ion beams causes considerable activity in the various elements of the machine; hence, a good deal of attention was paid to radiation safety measures. In addition to providing special radiation-level monitoring facilities, at this installation all operations which might be attended by radiation hazards are mechanized and performed by remote control. When the machine was started, in addition to nuclear physics research, studies of the various processes which take place in the cyclotron itself were started.

In 1950, in order to carry out experiments free from the background of radiation of the cyclotron itself, the ion beam was extracted through the main shield into a special installation, located 12 m from the chamber. This installation has its own shield.

In addition to deuterons, α particles and molecular hydrogen ions, this machine has been used to accelerate protons and multiply-charged nitrogen ions.

Electromagnet. The magnetic circuit is a closed frame, rectangular in cross section, with pole pieces. The frame elements are fabricated from separate sheets of rolled steel 30 mm thick. The magnet pole pieces are made from forged pieces of "Armco" iron in the form of truncated cones. The diameter of the pole piece is 1500 mm. The electromagnet is air-cooled. The total weight is 330 tons. This magnet provides in the operating gap, which is 180 mm, a field intensity of 18,000 gauss.

Resonance System and Radio-Frequency System

The resonance circuit of the cyclotron consists of the dees and two quarter-wave terminated coaxial lines. The resonant system is fed from a multi-stage amplifier through two coaxial feeders which are inductively coupled to the resonant lines. The available output power of the generator is of the order of 120 kw. The generator can be driven by an independent oscillator or operated as a self-excited oscillator; in this case the feedback loop includes the resonant circuit of the cyclotron.

A special modulator makes it possible to work with pulse operation or cw-operation. When in operation the potential difference between the dees is of the order 160-170 kv. The peak value of the potential of the dee in which the ions are extracted from the source is stabilized. There is a special setup for shielding the generator and dees in order to make tests in the chamber. The resonant lines operate over wave lengths ranging from 26 to 33 m. The electrical length of each line is adjusted by a grounding bar which is moved by an electric motor. In addition, there are two trimmer condensers which are located in the acceleration chamber and controlled remotely.

Center Part of the Cyclotron. The initial motion of the ions plays an extremely important role in the acceleration process. Calculations were carried out which delineated the dependence of ion phase in the first accelerating cycles on the width of the accelerating slit and the potential difference between the dees. It was shown (1950) that when a wide slit is employed there is a phase bunching of the ions similar to that which takes place in a syncrocyclotron. As a consequence, the phase differential of the majority of ions, after two or three acceleration cycles, becomes approximately zero. This situation leads to a considerable ion loss in the central part of the cyclotron. In order to inhibit the ion phase bunching, the horizontal and vertical distances between the edges of the dees were reduced by means of special shoulders. (The shoulders on the dees extended out to a radius of 20 cm). In order to reduce the energy spread in the output beam, ion extraction was carried out in one dee.

In order to improve the focusing action in the first acceleration cycle, the central part of the shoulder was subsequently replaced by a flat electrode in order to eliminate the inhomogeneity in the electric field which tended to defocus the ion beam in the vertical direction.

In 1953 an arc-type, ion source with a slit, was developed by the authors. As a supplementary means of improving the stability of operation of the cyclotron, the discharge current of the arc source was stabilized.

The Magnetic Field of the Cyclotron and Corrections. The motion of the particles in the later accleration cycles is determined chiefly by the magnetic field of the cyclotron. The absolute value of the magnetic field intensity was measured, with the cyclotron in operation, by means of a magnetometer which made use of a nuclear resonance absorption.

The magnetic field was kept constant by stabilizing the current in the windings of the electromagnet. In addition to current stabilization, in 1949-1950, a field stabilizer was developed and tested which made use of a specially constructed magnetic sensing unit which was placed in the fringing field of the magnet.

To investigate the inhomogeneities in the magnetic field, in 1950 a special device was constructed, in which a ballistic measurement method was used. To improve the accuracy of the measurements a sensing unit with a pendulum-bob coil and a sensitive electronic flux meter were developed. Using this instrument it was possible to carry out separate highly accurate measurements of the radial and vertical components of the magnetic field intensity.

A study was made of the effect of inhomogeneities in the magnetic field on the vertical displacement of the beam; this was done by installing auxiliary windings, connected in opposition, at the poles of the electromagnet. Using these windings it was possible to vary the position of the beam of accelerated particles in the vertical direction without disturbing the ion-acceleration resonance conditions. The ejection radius of the cyclotron is 670 mm. The total decay of the field at the terminal radius is 1.7%.

The magnetic field corrections were introduced through the use of internal rings and discs positioned in the gaps between the full pieces and of the electromagnet and the covers of the chamber. The gaps were 35 mm. The azimuthal corrections for the magnetic field were provided in the same gaps by means of iron elements, which were moved radially by remote control or by auxiliary coils.

Acceleration Chamber, Resonance Lines, and the Dees

The cyclotron chamber with the resonance lines was mounted on a self-powered trolley so that it was possible to carry out the basic assembly and disassembly operations on these components with a powered driving system (Fig. 1). The body of the chamber, fabricated from brass, provides the necessary structural rigidity. The end caps of the chamber, made from "Armco" steel, are 1500 mm in diameter and 100 mm thick. In one side of the chamber there is a rectangular window through which it is possible to pass the dees into the chamber. In

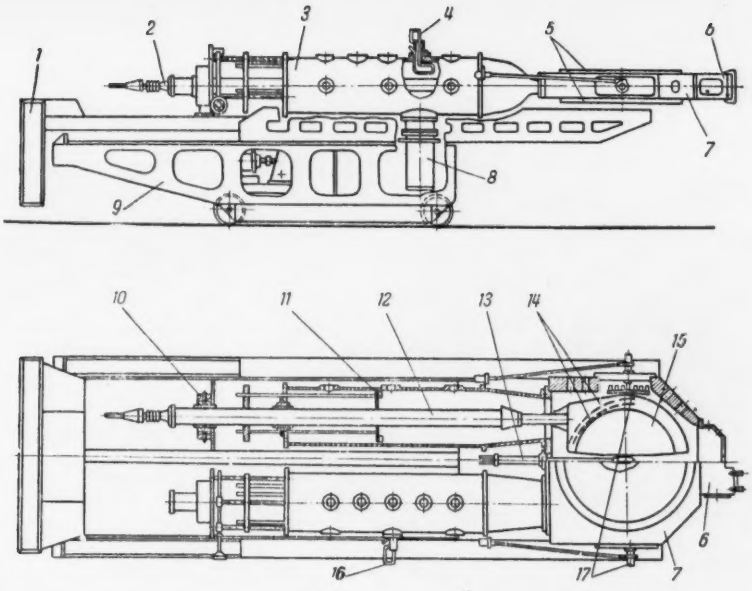

Fig. 1. Diagram showing the arrangement of the chamber and resonance lines on the self-powered trolley. 1) Water distribution manifold; 2) insulator; 3) tank for the resonance line; 4) coupling loop; 5) chamber cover; 6) compartment for deflection system; 7) chamber; 8) pump; 9) self-powered trolley; 10) adjustment device; 11) shorting bar; 12) support rod; 13) source; 14) deflection system; 15) dee; 16) feedback loop; 17) trimmer condensers.

the other side of the chamber there is a compartment in which the beam is extracted. There are vacuum locks in the chamber which make it possible to introduce measuring probes and internal targets without breaking the vacuum.

The tanks for the resonance lines are made from copper and are cooled by distilled water. There are a number of ports in the tanks through which it is possible to set the coupling loop at the desired point.

The dees are fastened to the ends of rods which pass through the tanks. These rods are made from copper tubing and have a heavy-duty water cooling system. The high voltage for the deflection system passes through one of these rods inside an insulated tube. The dees are of riveted construction with strengthening and water cooling. The deflection system is located in one of the dees. The dees are made of copper. The dee clearance is 60 mm. The coarse control of the position of each dee is accomplished where the dee joins the rod. Fine control is realized without breaking the vacuum by a special mechanism at the other end of the rod.

Vacuum System. The resonance lines and the acceleration chamber are evacuated by three oil diffusion pumps. Taking into account the losses in the traps and valves of the system, the total capacity of the pumps is 3000 liters/sec. The pumps which are used are modernized versions of the MM-1000. The forevacuum is provided by a number of mechanical pumps (VP-1) which are located in an isolated installation. All valves are controlled remotely. In case of vacuum failure these valves operate automatically. The vacuum at any point in the system can be determined remotely by ionization, magnetic-discharge or thermocouple gauges. All vacuum seals are made with rubber gaskets.

Deflection System and Beam Focusing on a Remote Target

The beam of charged particles is deflected by the usual electrostatic system. The high-potential plate of the system is made of copper and installed in the dee by means of two insulators and is water cooled. The other plate is fastened directly to the lower part of the dee. At the edge, this plate, made from tungsten or graphite, is approximately 0.8 mm thick. The operating voltage applied to the deflection system is never greater

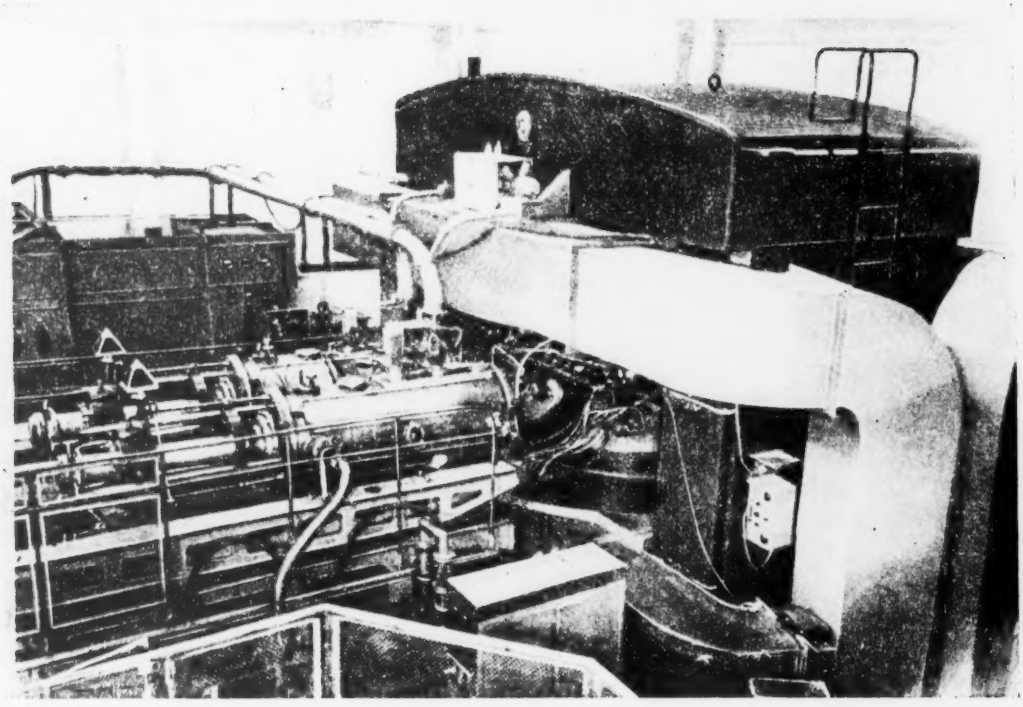

Fig. 2. General view of the machine from the resonance-lines side.

than 70 kv. The ejection efficiency for this system varies from 25 to 30%. In addition, a deflection system with an inhomogeneous electric field was tested, which, in addition to deflection, provided horizontal focusing of the beam. The initial tests with this sytem were very encouraging and at the present time work is being carried out on the development of a device in which the surface of the electrostatic plates is hyperbolic in cross section.

It is also proposed to provide supplementary focusing of the deflected beam by introducing iron elements of appropriate shapes in the fringing field of the magnet.

The beam of charged particles which is extracted from the chamber is focused both in the horizontal and the vertical directions. The focusing in the horizontal direction is realized by means of a sectored electromagnet while the vertical focusing is provided by a special electrostatic device. The electrostatic system increases the density of charged particles in the beam at the target by a factor of 10. The fact that focusing of the extracted beam is carried out separately for the horizontal and vertical directions means that it is possible to make the adjustments of the focusing system in these directions almost independently. The cross section of the focused beam at a remote target without a diaphragm is $4 \cdot 2$ cm^2 with 90% of the current incident on an area 2×1.5 cm^2. By changing the potentials in the electrostatic system it is possible to control the density of the beam at the target.

The energy spread in the focused beam is of the order of $\pm$ 1% of the mean value of the energy.

The vacuum tube which connects the cyclotron chamber with the remote target is evacuated by separate pump.

The cyclotron is provided with a number of measuring instruments which are remotely controlled, thus making it possible to study the intensity distribution over the cross section of the beam.

In changing over from deuteron acceleration to acceleration of molecular hydrogen ions, a sizeable background of deuterons was observed; this may be detrimental in certain nuclear studies. In order to remove this background, an aluminum foil 1-2 mμ thick was set up in front of the sectored focusing magnet at which the

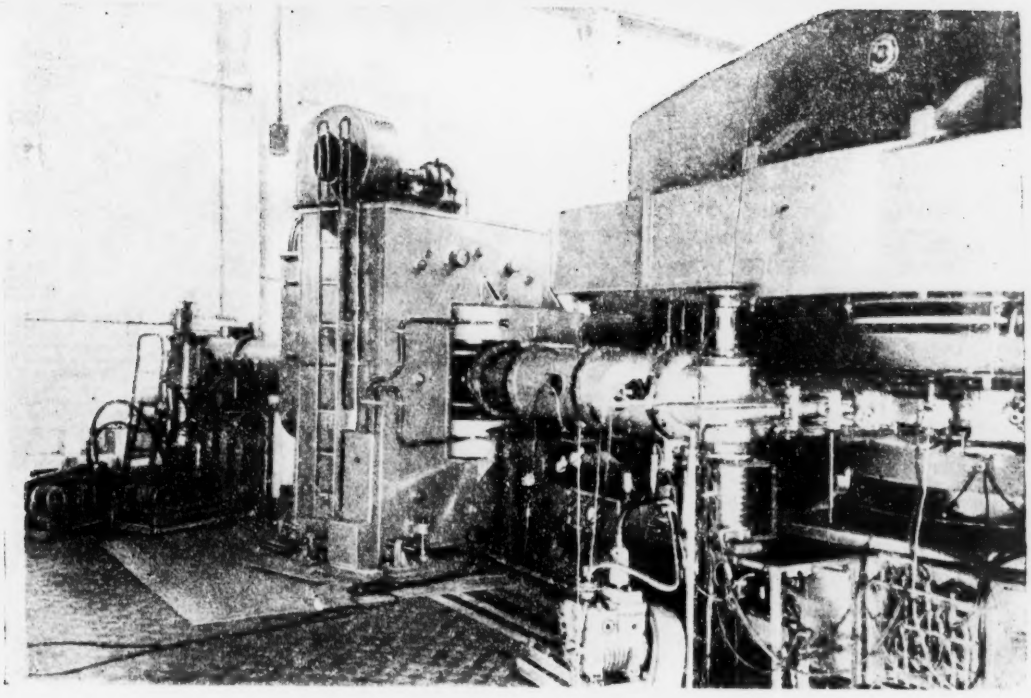

Fig. 3. General view of the machine from the beam-injection side.

the stripping of the molecular hydrogen ions occurs. The deuterons and protons are deflected by the focusing magnet at different angles; thus, using this system, only protons are able to reach the remote target.

External views of the cyclotron are shown in the photographs (Figs. 2 and 3).

CONCLUSION

In conclusion, it should be noted that using this machine we have accelerated protons to 12.2 Mev, deuterons and molecular hydrogen ions to 19.6 Mev, α-particles to 39.2 Mev and sextuply-charged nitrogen ions to 120 Mev. The following currents were obtained with 12.2-Mev protons: at the terminal radius, 1 ma; in the deflected beam, 250 μa; and at the remote target, 30 μa. The maximum current density achieved at the remote target with protons was 15 $\mu a/cm^2$ and with 19.6-Mev deuterons, 4 $\mu a/cm^2$.

At the present time our group is carrying out a study on the development of a deflection system with focusing properties. Strong focusing for the accelerated particle beam is being introduced, starting at small radii. Methods of obtaining a monochromatic beam of charged particles and methods for correcting the magnetic field are being developed which will make it possible to realize a wide variation in ion energy. A good deal of attention is being devoted to stabilizing the cyclotron parameters. The individual questions touched upon in this paper will be published in greater detail.

In conclusion we wish to acknowledge the collaboration, in the design and construction of this machine, of our colleagues D. V. Efremov, E. G. Komar, I. F. Malyshev, N. A. Monoszon, M. A. Gashev, and N.S. Strelstov at the Scientific Research Institute for Electrophysical Apparatus, Ministry of Electrical Industry. The initial startup operations were carried out with the active assistance of Yu. M. Pustovoi, A. P. Tsitovich, and A. V. Chestnoi.

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INVESTIGATION OF THE SYSTEM ZIRCONIUM–TANTALUM

V. S. Emelyanov, Yu. G.Godin and A. I. Evstyukhin

The methods of metallography, thermal analysis, electrical resistance, and x-ray phase analysis were used to study the system zirconium–tantalum, and the phase diagram was constructed. The diagram for the zirconium–tantalum system is of the eutectic type with limited solubility. The maximum solubility of tantalum in α-zirconium at 790°C is less than 22 atomic %, and in β-zirconium at 1585°C it is 16 atomic %. The maximum solubility of zirconium in tantalum at 1585°C is 17 atomic %. The eutectic corresponds to 1585°C and 34 atomic % tantalum. At 790°C and 7 atomic % tantalum a eutectoid transition of the solid solution based on β-zirconium takes place.

INTRODUCTION

Only fragmentary information is available in the literature on zirconium–tantalum alloys.

Anderson, et al. [1] studied cast alloys of zirconium with up to 30.3% tantalum, made in graphite crucibles under vacuum from spongy zirconium and sheet tantalum. The alloy containing 5.3% tantalum has a one-phase structure, while the alloy with 9.7% tantalum is apparently a solid solution at the melting temperature and two-phase in the solid state. The alloy with 14.1% tantalum contains about 20% of a second phase (eutectic) concentrated at the grain boundaries. At 20.8% tantalum this phase occupies the entire field. The alloy with 30.3% tantalum consists mainly of a eutectic and a light-colored component in the form of dendrites, the content of which does not exceed 10%.

According to Pfeil [2], the new component in the alloy with 14.1% tantalum is hardly a eutectic, in view of the decrease of hardness reported by Anderson, et al., while in the alloy with 20.8% tantalum the β phase can be preserved down to room temperatures. He also states that the alloy with 30.3% tantalum possibly consists of a β-solid solution with dendrites of an intermediate phase or of a solid solution rich in tantalum.

Litton [3] states that the cast alloy containing 12.5 wt.% of tantalum has a homogeneous structure.

Keeler [4] found that an alloy of zirconium with 2.7 atomic % of tantalum has a transition range between 807 and 852°C. This indicates a lowering of the transition temperature of zirconium on addition of tantalum.

Schwope [5] considers that tantalum should form a eutectoid with zirconium, widen the β region, and lower the allotropic transition temperature. According to his data, the maximum solubility of tantalum in α-zirconium is 5 atomic %.

The possibility of eutectoid formation in the zirconium–tantalum system is also noted in Lustman's review [6].

Methods for Preparation and Investigation of the Alloys

The preparation of zirconium–tantalum alloys is difficult because of the high melting points of these metals and their high activities when hot. These difficulties are avoided by fusion of the specimens in the MIFI-SM-3 arc furnace with a cooled copper crucible (Fig. 1).

Fusion of the specimens was performed in an atmosphere of argon of "pure" grade. To remove traces of

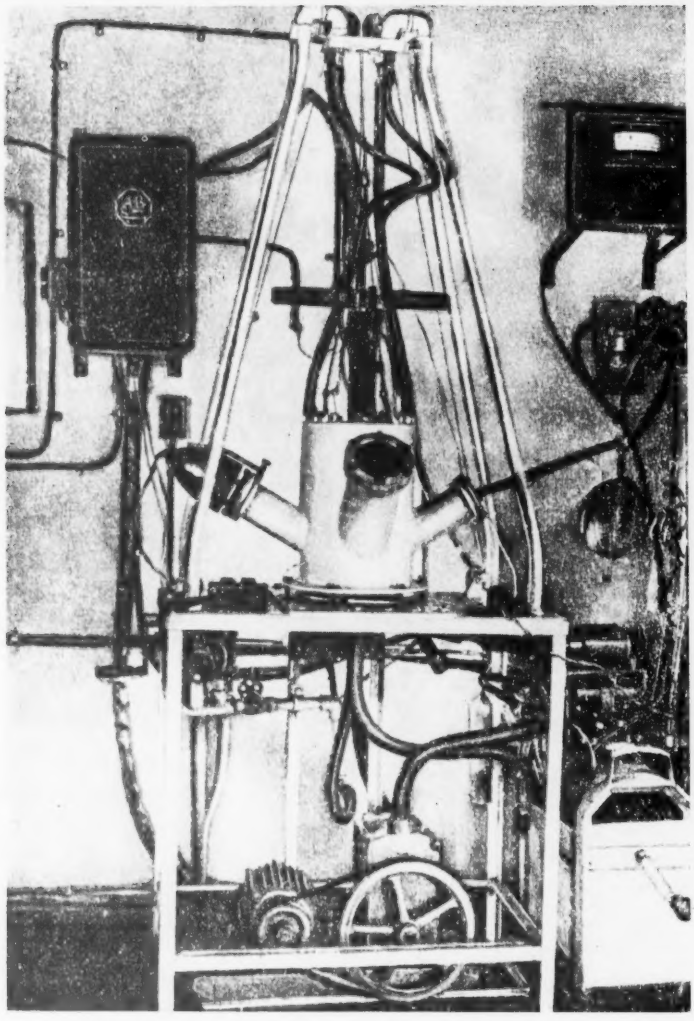

Fig. 1. MIFI-SM-3 arc furnace.

oxygen and nitrogen, the argon was passed over calcium shavings heated to 800°. Additional "fine" purification of the argon was effected by fusion of iodide zirconium getter.

The alloys were made from rods of iodide zirconium of the following percentage composition: Zr – 99.6; Cl < 0.0025; W < 0.01; Ni – 0.001; Cr < 0.03; Fe – 0.022; Ca < 0.005; Si < 0.005; C – 0.05; Cd < $3 \cdot 10^{-5}$; Hf – 0.05; Mn – 0.002; N – 0.014; Ti – 0.0034; Cu < 0.001; Mo < 0.01.

The tantalum ribbon had the following percentage composition: Ta – 99; Nb – 0.5; Ti – 0.06; W – 0.02; Fe < 0.05; Mo – 0.03; Si < 0.1.

Weighed portions of the metals, charged into the furnace, were melted together, then cut into several portions by means of the arc and again melted. This operation was repeated 3-4 times. Homogeneity of the composition of the alloys was checked by metallographic investigations of different parts of the ingot, and proved to be satisfactory.

Contamination of the alloys by gases during fusion was controlled by measurements of the hardness of a control specimen of iodide zirconium which was melted at the same time as a batch of alloy specimens. 36 dif-

ferent alloys were made for metallographic analysis, and 13 alloy specimens in the form of rods 60 mm long and 8-13 mm in diameter were made for electrical resistance measurements. All the alloys were chemically analyzed.

The cast alloys were given a homogenizing annealing treatment at 1200°C, while for investigations of phase equilibria at high temperatures they were subjected to isothermal annealing followed by quenching. The annealing conditions are shown in Table 1.

Before the annealing the specimens were cold-pressed as much as possible and placed in evacuated quartz bulbs. For annealing above 1000°C the bulbs were filled with argon, and the specimens were enclosed in cases of sheet molybdenum.

As a control of the annealing medium, a piece of iodide zirconium was placed in each bulb. At the end of the annealing the specimens were quickly withdrawn from the surface by tongs and quenched by breaking the quartz bulb under water. Microscopical analysis of alloys quenched in water from a temperature of 1425°C, and of alloys cooled by switching off the TVV-2 furnace, showed no differences in microstructure, therefore the second procedure was used for tempering specimens from a temperature of 1550°C.

TABLE 1

Annealing Conditions

Temperature*, °C	Annealing time, hours	Tantalum content in alloys, %
1550**)	2	70—99
1425**)	3	70—99
1425	3	0.25—99
1200	80	70—99
1200	16	0.25—80
1000	40	0.25—80
900	70	0.25—80
830	100	0.25—80
800	150	0.25—80
780	200	0.25—80
760	250	0.25—80
740	350	0.25—80
700	600	0.25—80
600	600	0.25—80

* Temperature fluctuations ± 5°C.

** Annealed in TVV-2 furnace [7].

The metallographic sections were first subjected to the usual polishing and were then polished mechanically with a cloth moistened with a fine suspension of chromium oxide in water. The etching agent described by Domagala, et al. [8] – a mixture of 20% HF and 20% HNO_3 dissolved in water or glycerol – proved suitable for most of the sections. Alloys close to the eutectic composition were strongly oxidized by this etching medium. For these, the hydrofluoric acid content was decreased to 5%. Alloys rich in tantalum were satisfactorily etched by a mixture of 90% HF and 10% H_2SO_4.

Unannealed powder samples taken from cast and quenched specimens of various compositions were subjected to x-ray phase analysis. An RKU-1 camera with copper K_α radiation filtered through nickel was used.

Thermograms were obtained by means of Kurnakov's recording pyrometer up to 1000°C only. Each specimen was placed with a standard in a special nickel cell fixed in the alitized, thickened lower portion of a steel vessel. The upper end of the vessel was cooled by water and hermetically closed by a lid with holes for thermocouples. The steel vessel was heated in a resistance shaft furnace. The heating and cooling (after switching off) was carried out under vacuum at 10^{-3} mm at a rate of 6 deg/min.

Determination of the Solidus and Liquidus Lines

The points on the solidus were determined from the start of appearance of visible signs of fusion, and those on the liquidus from conversion of small pieces of the alloys into droplets [9].

Faceted pieces of the alloys 3-5 g in weight were placed on the edges of a zirconium oxide support and introduced into a TVV-2 furnace [7]. They were then heated to a temperature known to be lower than the melting point, and held at that temperature for 15 minutes. The temperature was measured both by an optical pyrometer and by a platinum/platinum–rhodium thermocouple introduced into the furnace through a rubber seal. The hot junction of the thermocouple was protected by a zirconium oxide tip and fixed in the center of the support. In absence of signs of fusion, the temperature of the specimens was raised by 30-40°C; the specimens were again held at this temperature, etc. This procedure was repeated until the first signs of fusion, taken as the solidus point, appeared. The temperature was then raised until droplets were formed; this was taken approximately as the liquidus point.

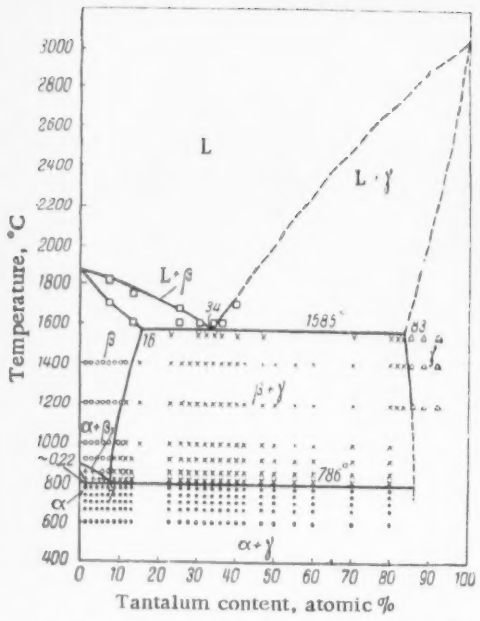

Fig. 2. Phase diagram for the zirconium–tantalum system. □) Determinations of solidus and liquidus; ○) one-phase α-alloy; ×) two-phase alloy, β + γ; +) two-phase alloy, α + β; ●) two-phase alloy, α + + γ; △) one-phase γ-alloy.

Results of Investigations of the Zirconium–Tantalum System

Microscopical examinations of the structure of cast alloys showed the existence of a considerable region of solid solutions of tantalum in zirconium, a eutectic, and a region of solid solutions of zirconium in tantalum, with a dendritic structure in the cast state.

X-ray phase analysis showed that only two phases were present in the system: α-zirconium and the β-phase, which is a tantalum-based solid solution; attempts to stabilize the β-phase of zirconium at room temperature were not successful.

Microscopical analysis of cast and quenched alloys and data on the temperatures of the start of melting of the alloys showed that the eutectic lies at 1585 ± 15°C with 34 atomic % tantalum (Fig. 2). Figure 3 shows the eutectic structure of the alloy with 34% tantalum, rapidly cooled in a TVV-2 furnace from 1570°C after 15 minutes at that temperature.

Attempts to quench hypoeutectoid alloys from the melting point of the eutectic were not successful, and the maximum solubility of tantalum in β-zirconium, 16%, was determined by extrapolation of data from 790 to 1425°C by means of L. F. Schroeder's equation. Figure 4 shows the structure of the converted β-phase for an alloy with 10% tantalum, and Fig. 5, the two-phase structure (β-zirconium plus γ-phase) of an alloy with 12.5% tantalum, quenched from 1200°C after isothermal annealing.

The maximum solubility of zirconium in tantalum was determined metallographically to be 17 atomic %. Figure 6 shows the structure of a solid solution of zirconium in an alloy containing 83 atomic % of tantalum after quenching from 1550°C.

Alloys with a few atomic percent of tantalum showed eutectoid decomposition, illustrated in Figs. 7 and 8. Figure 7 shows the two-phase annealing at 800°C, consisting of the α-phase and a metastable β-phase. Figure 8 shows the structure of the same alloy quenched from 780°C. This consists of primary α-phase grains with the eutectoid on its boundaries. Microscopical analysis of alloys quenched from 800°C showed that the composition of the eutectoid corresponds to an alloy with 7 atomic % tantalum. The structure of this alloy, quenched from 780°C, is shown in Fig. 9. Metallographic data on alloys quenched from 800°C and lower in 20-degree steps showed that the eutectoid decomposition temperature is 790 ± 10°C. These results were confirmed by thermal analysis. An examination of the x-ray diagrams for alloys containing 1, 2, 3, 4, and 6 atomic % tantalum quenched from 780 and 800°C showed that γ-phase lines were present only in alloys quenched from 780°C, indicating eutectoid decomposition. It must be pointed out that the back lines in the x-ray diagrams of alloys quenched from temperatures above the eutectoid were very diffuse.

The maximum solubility of tantalum in α-zirconium was found to be very low. On quenching from 800°C, the structure of the alloy with 0.25% tantalum was found to contain slight inclusions of the metastable β-phase (Fig. 10). The metastable β-phase was not found in alloys with 0.20 and 0.15% tantalum. No appreciable changes in the lattice parameters were found in the x-ray diagrams of alloys with 0.15, 0.20, and 0.25 atomic % of tantalum quenched from 780°C. It was therefore assumed that the maximum solubility of tantalum in zirconium does not exceed 0.22 atomic % of tantalum.

These results were used to construct the phase diagram for the zirconium–tantalum system (Fig. 2), which shows the metallographic analysis data and the solidus and liquidus determinations.

Fig. 3. 34 atomic % tantalum. Annealed for 15 minutes at 1570°C. Eutectic β-Zr + γ. Etching agent 20% HNO_3 and 5% HF in glycerol. x 500.

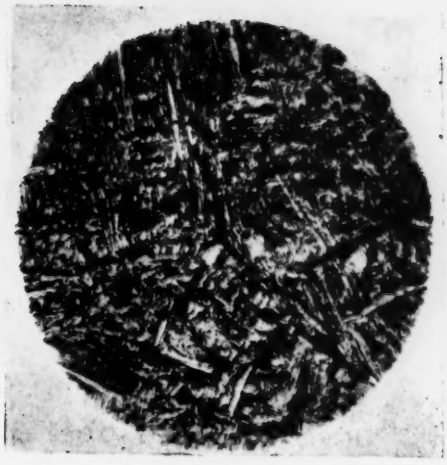

Fig. 4. 10 atomic % tantalum. Quenched from 1200°C. Acicular grains of converted β-phase. Etching agent 20% HNO_3 and 20% HF in water. x 100.

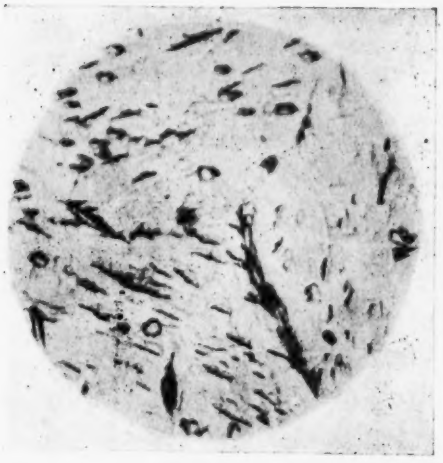

Fig. 5. 12.5 atomic % tantalum. Quenched from 1200°C. Decomposed β-solid solution and deposits of γ-phase. Etching agent 20% HNO_3 and 20% HF in water. x 500.

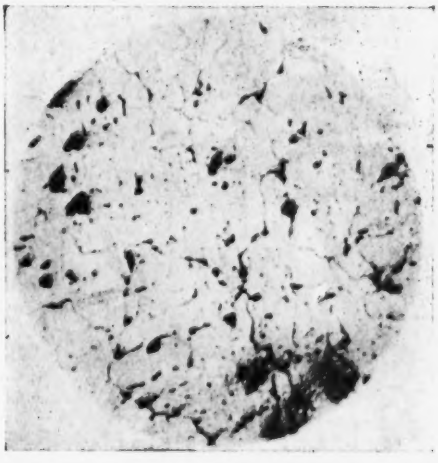

Fig. 6. 83 atomic % tantalum. Quenched from 1550° C. γ-solid solution. Etching agent 90% HF and 10% H_2SO_4. x 200.

To verify this phase diagram, electrical resistance measurements were performed on alloy specimens cast and quenched from 1200 and 700°C after being kept at these temperatures for 40 and 100 hours, respectively. The resistances were measured by means of the Thomson double bridge.

Specimens of the original metals, annealed for 40 hours at 1200°, were found to have the following resistances: zirconium $48.5 \cdot 10^{-6}$ ohm · cm, and tantalum $15.6 \cdot 10^{-6}$ ohm · cm.

Curves showing the electrical resistance of the alloys as a function of the tantalum content (Fig. 11), both cast (Curve I) and quenched from 1200°C (Curve II), which is above the eutectoid temperature, have a maximum at 10-20 atomic % of tantalum. This maximum is probably due to the martensitic character of the transition during quenching, found in zirconium alloys. The right-hand part of the curves shows a well-defined drop, due to formation of solid solutions of zirconium in tantalum. The regions in which the solid solutions exist, found

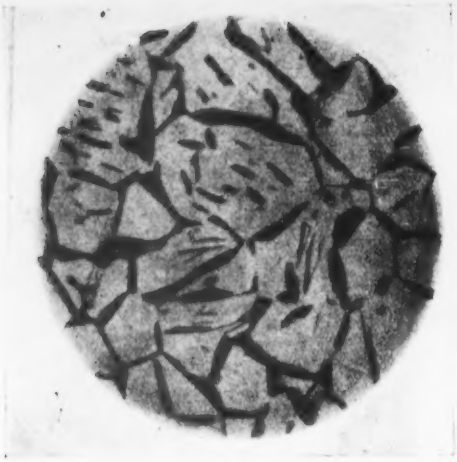

Fig. 7. 2 atomic % tantalum. Quenched from 800°C. α-phase and metastable β-phase. Etching agent 20% HNO_3 and 20% HF in water. x 200.

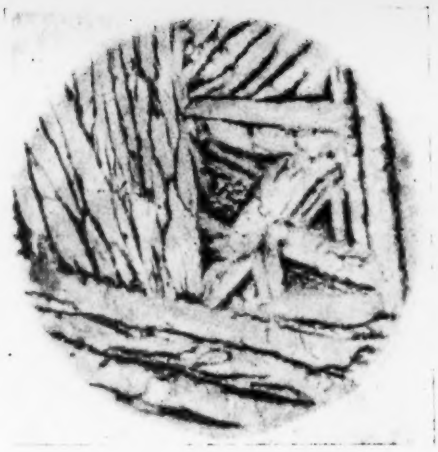

Fig. 8. 2 atomic % tantalum. Quenched from 780°C. Primary grains of α-phase and eutectoid. Etching agent 20% HNO_3 and 20% HF in water. x 500.

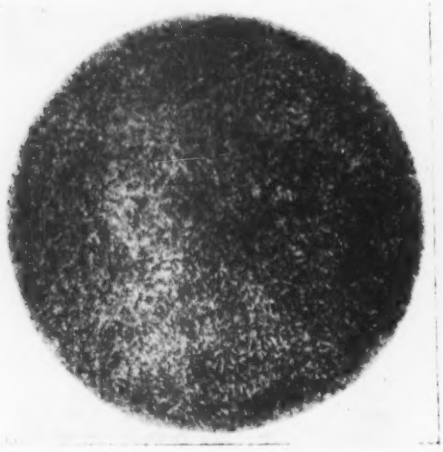

Fig. 9. 7 atomic % tantalum. Quenched from 780°C. Eutectoid $\alpha + \gamma$. Etching agent 20% HNO_3 and 5% HF in glycerol. x 500.

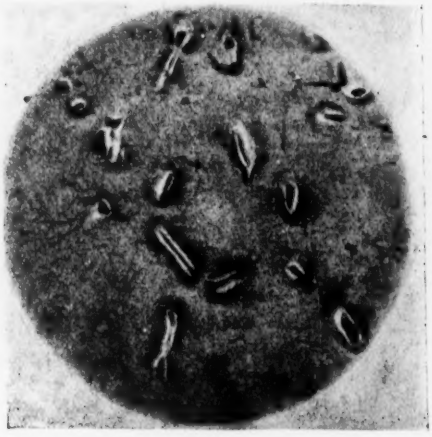

Fig. 10. 0.25 atomic % tantalum. Quenched from 800°C. α-phase and metastable β-phase. Etching agent 20% HNO_3 and 20% HF in water. x 200.

from Curve II, coincide with the solubility data found microscopically at 1200°C. The curve for the cast alloys (I in Fig. 11) in its general features is similar to the curve for alloys quenched from 1200°C (II), and differs from it only in the height of the maximum. This indicates that the cast alloys were quenched from temperatures above the eutectoid decomposition temperature.

Curve III (Fig. 11) for alloys quenched from 770°C is characteristic of alloys in the equilibrium state, and confirms the metallographic data on the low solubility of tantalum in α-zirconium.

In addition, the hardness of zirconium–tantalum alloys quenched from 770 and 1200°C was determined. Figure 12 shows the hardness of the alloys as a function of the tantalum content. The curves show that the hardness of the alloys increases with increasing tantalum content, while alloys quenched from 1200°C (Curve I) show a maximum which, as in the resistance curves, is associated with a transition of the martensitic type.

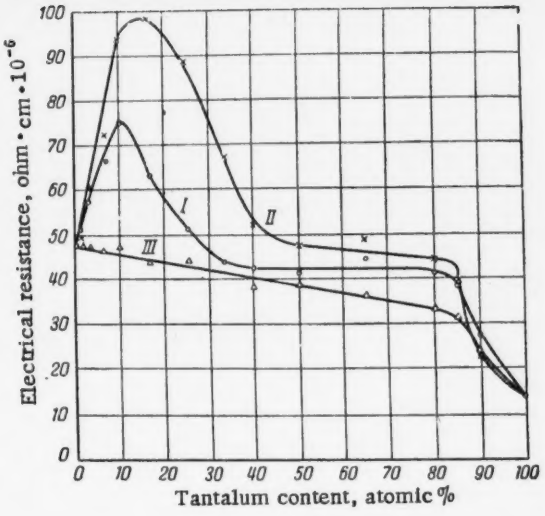

Fig. 11. Electrical resistance as a function of the composition of zirconium–tantalum alloys. I) Cast alloys; II) alloys quenched from 1200°C; III) alloys quenched from 770°C.

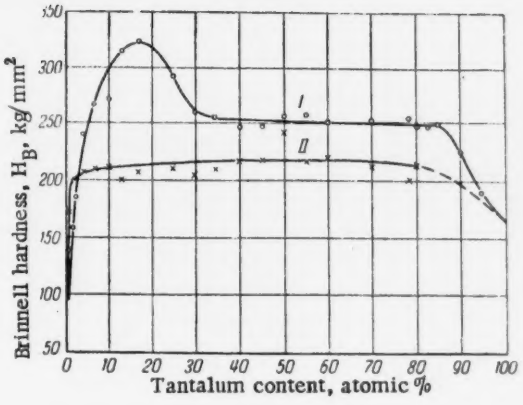

Fig. 12. Hardness as a function of the composition of zirconium–tantalum alloys. I) Alloys quenched from 1200°C; II) alloys quenched from 770°C.

SUMMARY

Metallographic, x-ray, and thermal analysis methods were used to study the system zirconium–tantalum and to plot the phase diagram. It was found that:

1) there is a eutectic of solid solutions based on β-zirconium and tantalum at 1585 ± 15°C and 34 atomic % of tantalum;

2) the maximum solubility of tantalum in β-zirconium is 16 atomic% at 1585°C;

3) the maximum solubility of tantalum in α-zirconium does not exceed 0.22 atomic % at 790°C;

4) the solubility of zirconium in tantalum at 1585°C is 17 atomic %;

5) there is a eutectoid transition at 790 ± 10°C and 7 atomic % of tantalum.

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QUANTITATIVE RADIOMETRIC MEASUREMENT OF RADIOACTIVE ORES IN THE NATURAL OCCURRENCE

V. L. Shashkin

First Report

The measurement of gamma radiation of radioactive ores in the natural deposit – directly in the face of a mine working or in a bore hole – permits determination of the radioactive element content in ores without collection of test samples and without chemical analyses.

The accuracy of quantitative measurement by gamma rays depends to a considerable degree on correct interpretation of the spectral content of the gamma radiation measured. The gamma-ray spectra of radioactive ores is determined by the process of radiation dispersion and depends on the content of the ore. The intensity of gamma radiation registered by an ore seam depends on the cathode material of the counter (tungsten, copper, graphite) as a consequence of the difference in spectral sensitivity of various counters. The relationship of gamma – radiation intensity during measurement with a Geiger counter with various cathodes permits one to characterize the spectral composition of the ore's gamma radiation.

In order to express the results in general units, microroentgens per hour, the radiometers are calibrated with an exact standard, but the calibration method does not exclude the radiometer reading dependence on the spectral sensitivity of the counters.

In this article are determined the important conversion coefficients connecting gamma-radiation intensity with the content of radioactive elements in ore (see the table) during measurements on the ore seam surface or in borings. During measurements in borings the reverse dissemination of gamma rays having low energy is of great importance.

By use of these coefficients calculations of the radioactive element content in ore from counter readings are carried out.

The development of the gamma method has, in recent years, led to working-out of radiometric assaying and gamma core sampling methods, which make possible determination of radioactive element content, from measurement of gamma radiation of ores in their natural occurrence, with accuracy sufficient to take the place of the normal assaying. These methods have found wide application in prospecting for uranium deposits and in their exploitation.

The general principles of radioactivity measurement of ores and rocks in the deposit and also the methods and techniques of gamma-ray testing of bore holes are adequately treated in the literature [1, 2]. The methods of radiometric assaying and of quantitative interpretation of gamma-ray core sampling results have as yet not been described.

The theory of gamma-radiation penetration through matter is worked out in detail by a number of foreign investigators [3-5], but further development of these investigations as applied to qualitative radiometric measurements is presented for the first time in this article.

The Physical Basis for Quantitative Measurement by Gamma Radiation

Basic Experiments. The spectral composition of gamma radiation of uranium and thorium ores in large masses is determined not so much by primary gamma radiation as by dispersed gamma rays which form in the process of multiple dispersion in the rock itself. The process of gamma-radiation dispersion during passage of the gamma rays from the exact source through thick layers of dispersing material is considered in detail by a number of authors [3-5].

The necessity for taking into account, during quantitative gamma measurement, of gamma-ray scattering in the radioactive rock itself was indicated in 1951-1952 by the author and by E. E. Shchelkov. The dispersion determines the spectral composition of the gamma rays of radioactive rock and, it follows, also the gamma-radiation intensity registered by the type of counter used.

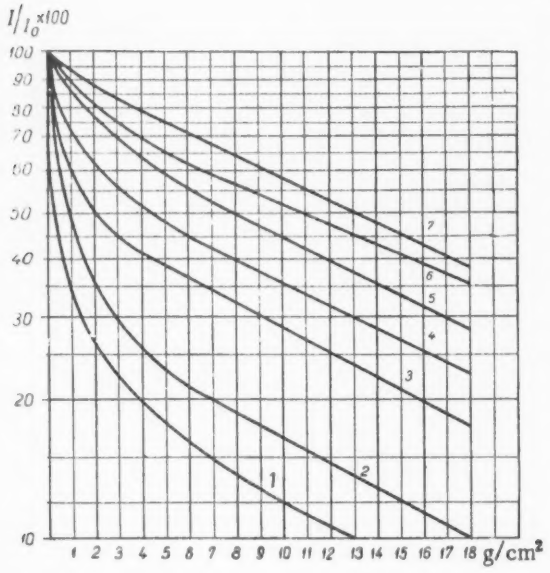

Fig. 1. Curves of gamma radiation weakening in cylindrical lead filters, from seams of uranium ore measured with various counters. Aluminum sleeve thickness 1 mm. 1) Counter TC, coal with 16% ash; 2) counter TC, silicate rock; 3) counter CC, coal with 16% ash; 4) counter CC, silicate rock; 5) counter GC, coal and silicate rock; 6) counter CC, standardization with a radium point source; 7) counter GC, standardization with a radium point source.

The qualitative characterization of the spectral composition of gamma radiation in radioactive ores may be obtained by experiments on the weakening of gamma radiation in a cylindrical lead filter slipped over the counter sleeve.

With complex spectral composition of the gamma radiation, the intensity registered by various types of counters depends on the spectral sensitivity of these counters: the higher the atomic number of the counter's cathode material, the greater its sensitivity to low-energy gamma quanta [6]. In the high energy region (more than one million electron volts) the sensitivity of most counters is roughly proportional to the gamma quanta energy.

The curves of weakening, presented on the graph, were taken on the patterns of uranium ore bodies by three types of gas-filled counters, shielded by an aluminum sleeve. The cathode of counter TC was tungsten, of CC, copper, and of GC, graphite.

The sharp reduction of gamma radiation with use of the lead filter (on the order of 2 g/cm^2) during measurements with counter TC – very sensitive to soft gamma rays – shows that in the gamma-ray spectrum of the ore seam are many soft components which are almost completely absorbed by this filter. The influence of soft gamma radiation is also noticeable on the curves recorded with counter CC, but it is hardly distinguishable in measurements with counter GC. Comparison of these data with the spectral sensitivity of the counters [6] may show that the energy of the soft gamma rays considered is less than 0.2 Mev.

The gamma-radiation spectral composition of an endless plane* depends on the average atomic number of the rock. This is apparent from the difference in the curves of weakening obtained with counters TC and CC on a silicate rock and on a low-ash coal. In coal, as in matter with low atomic number, the soft components of dispersed gamma radiation are developed to the greatest degree. With measurement of these rocks with counter GC, the difference in the gamma-radiation weakening disappears. This indicates an identical spectral composition for the hard part of the gamma radiation.

From the general intensivity of gamma radiation registered by counter TC, the portion of soft gamma radiation which is absorbed by 4 g/cm^2 lead comes to 76% for measurements of uranium-containing coal and 69% for measurements of silicate rock. Measurements with counter CC for the same group of soft gamma rays come to 49% for the coal and 35% for the silicate rock. In the spectrum registered by counter GC, the portion of soft gamma rays amounts to 23% regardless of the character of the rock.

Thus, the difference in dispersion of gamma radiation in rocks with various average atomic numbers is definitive only in the soft part of the spectrum of dispersed gamma rays.

Theoretical Analysis of the Gamma-Radiation Spectrum of Endless Layers. The gamma-radiation spectrum of endless layers of uranium and thorium ores was considered from a theoretical point of view by G. M. Voskoboinikov in 1954. He showed that the intensity of dispersed gamma rays decreases rapidly with increase of the atomic number of the dispersing medium. With increase of the atomic number of the medium, the order of size of the dispersed gamma rays decreases, which influences the general intensity of the dispersed gamma radiation and is thus connected with an increase [sic] in the probability of photoelectric absorption.

In a medium with a low atomic number (less than 29) the spectral intensity of dispersed gamma rays reaches large values only in the comparatively narrow region of low-energy quanta (for granite – from 0.05 Mev to 0.3 Mev, for coal – from 0.025 Mev to 0.25 Mev), in which it exceeds the spectral intensity of high-energy dispersed gamma rays by 10 to 20 times.

The spectral distribution and intensity of soft dispersed gamma rays with energy quanta less than 0.5 Mev, for practical purposes, does not depend on the spectral composition of hard primary rays with energy greater than 0.5 Mev. On the other hand, the spectral intensity of dispersed hard gamma rays with energy above 0.25 Mev may, practically, be considered independent of the atomic number of the medium for mediums with atomic number less than approximately 29; for mediums with large atomic numbers the intensity of the hard dispersed gamma rays falls with increase of atomic number.

Theoretical analysis of dispersed gamma radiation permits us to give a qualitative characterization of the gamma-radiation spectrum of endless layers of uranium and thorium ores.

The hard gamma radiation of these layers, with energy greater than 0.5 Mev, is represented by a continuous spectrum of dispersed gamma rays of low intensity, on which background the intense primary gamma-ray lines are sharply distinguished. The intensity and spectral composition of the hard gamma radiation does not depend on the composition of the rock, except for extremely rich uranium and thorium ores (with content roughly greater than 7%). In this part of the spectrum the difference in the primary gamma radiation of uranium and thorium lines is perfectly preserved.

In the area of soft gamma radiation with energies less than 0.5 Mev, the intensity of dispersed gamma rays grows rapidly with decrease of energy quanta, and the monochromatic lines of primary gamma radiation are nearly completely lost on the continuous spectrum background. Practically speaking, the intensivity and spectral distribution of the gamma radiation in this area does not depend on the primary gamma radiation composition and appears identical for uranium and thorium ores.

From this it follows that for all rocks besides the very rich uranium and thorium ores, change in gamma-radiation intensity dependent on the rock composition takes place completely (for practical purposes) because of change of intensity of the softest gamma radiation, with energy quanta less than 0.25 Mev. From here follows

* For gamma rays, an endless plane is a radioactive layer for which an increase in size of the plane does not cause a corresponding increase in intensity of the measured gamma radiation.

the important practical property of independence of the gamma-radiation intensity from the composition of the radiation layer during recording of gamma radiation by counters which have low sensitivity for soft gamma rays (type GC), or which are shielded from soft gamma-ray penetration by a sufficiently thick sleeve of some material with a high atomic number.

Radiometer Calibration. When conducting quantitative gamma-radiation measurements it is important to obtain radiometer readings in common units. In 1947 V. I. Baranov, K. A. Shatskin, and V. L. Shashkin proposed a procedure for calibration with a point-source radium standard and accepted μr/hr (microroentgens per hour) as a unit of gamma-radiation intensity. Later the same calibration procedure was utilized by American geophysicists [2].

Radiometer calibration consists of measurements of gamma-radiation intensity from a standard at various distances between the standard and the counter. From this the intensity of gamma radiation for a given distance is calculated by the formula

$$I = 8 \cdot 5 \cdot 10^9 \frac{m}{r^2},$$

where m is the quantity of radium in the standard, in grams, and r is the distance in centimeters between the standard and the counter; the numerical coefficient is the gamma constant of radium, expressed in $\mu r \cdot hr^{-1} cm^2 g^{-1}$. The calibration may be carried out with a fixed distance between standard and counter but with varying standard strength.

Calibration conditions are selected so that the counter being calibrated registers only the primary gamma rays of the standard. Absence of the influence of dispersed gamma rays may be assured by shielding the counter and standard by cylindrical shields. If the counter is registering only primary gamma rays, the curves of weakening obtained when the counter is shielded and when the standared is shielded will correspond; when there is considerable influence of dispersed gamma radiation, the curve of weakening taken when the counter is shielded shows softer gamma radiation.

Because of the different spectral characteristics of counters with cathodes of different materials, their sensitivity to the gamma rays of the standard varies. Thus, with a 1 mm thick aluminum sleeve and identical sizes of counters in μr/hr we obtain: counter TC – 4-9.9 imp/min, counter CC – 4-4.7 imp/min, and counter GC – 4-5.3 imp/min.

The difference in spectral composition of the gamma radiation of the standard and the radioactive ore in the natural deposit leads to the circumstance that the gamma-radiation intensity of the same ore face is expressed by various numbers of μr/hr when measured with different types of counters or when measured with one counter with different thicknesses of radiometer sleeves. It follows that calibration of the radiometers gives only a convenient means of expressing the radiometer values in common units, microroentgens per hour, which are in this case only conditional and not absolute units of gamma-radiation intensity.

As regards the results of gamma-radiation intensity measurements with counters having different spectral sensitivities, the spectral composition of gamma radiation measured may be qualitatively described. For the spectral composition of the gamma radiation of a radium standard, the values, expressed in microroentgens per hour, are taken as equal for all types of counters. With measurement of gamma radiation of another spectral composition, the proportion of the intensities measured with such counters as TC and CC or CC and GC, expressed in microroentgens per hour, will be greater, the more soft components there are in the radiation measured. This ratio, sometimes conditionally called the spectral ratio, may serve as a characterization of the gamma radiation of radioactive rocks.

Gamma Radiation of Endless and Semi-Endless Uranium Ore Layers. For qualitative radiometric measurements of radioactive ores by their gamma rays, the correlation between the intensity of the gamma radiation measured on the surface of a uranium ore seam, which is endless in extent and thickness (a semi-endless ore layer) or measured within an uranium ore seam (an endless layer), and the content of uranium which is in radioactive equilibrium with the decay products, has great importance. Of considerable importance also is the dependence of these relations on the ore composition, the counter cathode material, and the thickness of the radiometer sleeve.

In the table are presented the average values for the coefficients of endless and semi-endless layers, expressed in microroentgens per hour for a content of 0.01% uranium in equilibrium; the values were obtained by

experiments on models – boxes filled with pulverized ore of known uranium content. The loss of radon from the ore was taken into account in processing the experimental data, and in several experiments practically nonemanating ore was used.

	Coefficients					
	1 mm thick aluminum sleeve			sleeve of 1 mm iron and 3 mm lead		
	GC	CC	TC	GC	CC	TC
Endless layer	89	144	234	70	74	77
Semi-endless layer	43	56	79	36	39	37
Coefficient of reverse dispersal of the rays	1.03	1.28	1.48	0.97	0.95	1.04

The sharp difference in the coefficients corresponding to measurements with counters having cathodes made of elements with small and large atomic numbers is a result of the large portion of soft gamma rays (with energies on the order of 0.1-0.2 Mev) in the gamma-radiation spectrum of an endless seam of uranium ore. For practical purposes counter GC does not register gamma rays of such energy; therefore, with it were obtained the smallest coefficient values. When measuring with the counter inclosed in the thick sleeve (1 mm iron and 3 mm lead), the soft gamma radiation practically does not penetrate through the sleeve, as a consequence of which the coefficients turn out to be nearly the same for all three types of counters.

Theoretical values for the coefficients of an endless layer were calculated by G. M. Voskoboinikov for rocks with different average atomic numbers and for recording of the gamma radiation with counters with copper and lead cathodes. Voskoboinikov showed that the coefficient of an endless layer is lower, the higher the average atomic number of the rock.

The experimental data presented in the table agree well enough with his calculations. Actually, the theoretical value for the coefficient of an endless layer of granite with a uranium content on the order of tenths of percent, with gamma radiation measurement by a counter with a copper cathode – equal to 140 μr/hr for 0.01% U – agrees with the corresponding experimental value (counter CC in an aluminum sleeve) within the limits of experimental error. For measurements with the lead counter the calculated coefficient value is 240 μr /hr for 0.01% U. The corresponding theoretical value for the spectral ratio is 1.73. If it is accepted that the spectral ratio changes in proportion to the difference of the atomic numbers of the cathode materials, then the theoretical value of the spectral ratio for measurements with counters TC and CC is equal to 1.63; the experimental value obtained was 1.66. The average atomic number of the rocks used in the tests was close to that of granite.

Reverse Dispersion of Gamma Rays.* Because of the geometrical conditions of measurement, the coefficients of an endless layer should be two times greater than the coefficients of a semi-endless layer. In fact, however, in measurements with counters sensitive to the soft gamma radiation the ratio of these coefficients turns out to be greater than two. This is connected with the influence of reverse dispersed gamma rays [7, 8], which are gamma rays dispersed at an angle greater than $\pi/2$ (the angle between the direction of the incident and the dispersed ray). In the table are shown the coefficients of reverse dispersed rays – the ratios of the coefficient of an endless layer to the doubled coefficient of a semi-endless layer. With a thin radiometer sleeve the coefficient of reverse dispersed rays decreases sharply with change from counter TC to counter GC, which shows the low energy of these gamma rays. In measurements with counters shielded by thick sleeves the coefficient of reverse dispersed rays is, within the limits of experimental accuracy, equal to one. In other words, the thick sleeve practically does not admit these rays; counter GC hardly registers reverse dispersed gamma rays.

The low energy of reverse dispersed gamma rays is confirmed also by comparison of the spectral ratios of measurements on the ore seam surface and in bore holes. Thus, the ratio of the coefficients of a semi-endless layer measured by counters TC and GC, shielded by a 1 mm thick aluminum sleeve, equals 1.84, and the corresponding ratio for an endless layer (measurements in a bore hole) equals 2.64.

Experimental and theoretical investigations of the gamma radiation of radioactive-ore layers have led to conclusions which have practical value for quantitative measurements by gamma rays:

1. In measurements with counters sensitive to soft gamma radiation and shielded only by a thin sleeve, one must take into account the dependence of the registered gamma-radiation intensity on the medial atomic

* Sometimes they are called secondary entry rays [7, 8].

number of the rock, on the material of the counter cathode, and on the thickness of the radiometer sleeve walk.

2. It is expedient to carry out quantitative measurements by hard gamma radiation, using for this counters which have low sensitivity to the soft rays (for example, type GC) or counters of any type which are shielded by a lead sleeve with thickness approximately 4 g/cm^2. In this case the intensity of gamma radiation for usual rocks (with average values for the atomic number) does not depend on the medial atomic number of the rock.

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Note: Photographs of radioactive ores (pitchblende with carbonates, autunite, phosphate of uranium, regenerated uranium black in barite, hydropitchblende with uranium hydrates, and phosphuranylite) were reproduced in color in the original journal. They are not reproducible by the multilith process. Hence, they are omitted in this translation – Publ.

DAMAGE TO PLASTIC SCINTILLATORS BY IONIZING RADIATION

I. M. Rosman and K. G. Zimmer

The intensity of the luminescence emission from plastic scintillators in which polystyrene is used as a base material is reduced as the doses of the α- and β-radiation absorbed by the scintillator are increased. Furthermore, irradiation is characterized by a reduced transmission of the luminescent light of the plastic scintillators which, however, is not sufficient to explain quantitatively the reduction in the intensity of emission which is observed. The reduction of luminescent yield is associated with radiation damage of the plastic scintillators. For 50% damage in plastic scintillators a dose of α-radiation of approximately $6 \cdot 10^9$ erg/g is required, that is, a factor of 50 greater than that required to produce the same damage in an anthracene single-crystal.

The practical importance of research into damage of scintillation plastics caused by ionizing radiation is obvious and hardly requires additional comment [1-3]. Moreover, an investigation of the damage mechanism has theoretical value, particularly in connection with the fact that plastic scintillators, in contrast to single-crystal scintillators (for example, anthracene), consist of several components so that it is possible to vary the chemical composition. From a study of the damage of plastic scintillators it should be possible to delineate the nature of the processes which occur when damage takes place in organic scintillators in general. At the present time, many of the details of this process are not understood [1, 4-6].

Method of Investigation. Work at this laboratory has been concerned with plastic scintillators of polystyrene with special luminescent additives, in particular, paraterphenyl (PT) and 1,1,4,4-tetraphenylbutadiene (TPB) [7-9], and also with plastic scintillators of pure polystyrene. The luminescence was measured with a photomultiplier (type PEM-19) and a mirror galvanometer. To observe the absorption and emission spectra a spectrophotometer (type SP-4) was used with various attachments. This same device was used as a monochrometer for exciting photoluminescence in desired parts of the spectrum.

The plastic scintillators were irradiated with α- and β-particles for which purpose preparations of Po^{210} and $Ce^{144}-Pr^{144}$ were used. The polonium was deposited on a silver disc approximately 5 mm in diameter. The dosage rate from the polonium source was determined by measuring the ionization current in a plane air-condenser using different field intensities (up to 2000 v/cm). The saturation current was obtained by extrapolation. The cerium-praesodymium preparation was a dry, almost weightless, sample and was contained in a flat cup of stainless steel, 8 mm in diameter and 2 mm high, with an aluminum window approximately 11 mg/cm^2 thick. The activity of these preparations was determined by comparison of the γ-radiation with a standard cerium-praesodymium source. All preparations which were used provided a dosage rate of approximately 10^9 erg/g-hour.

The plastic scintillators were small plates approximately 20 mm in diameter and approximately 0.5 mm thick at the center. Only a small circular section, 5 mm in diameter, at the center of the scintillator was irradiated and used in the subsequent investigation. As a rule the irradiation was carried out in a dessicator, that is, in dry air at a constant room temperature and in the absence of strong illumination.

Variation of Absorption of Light. There have been recent extensive studies of the effect of ionizing radiation on plastics [10] in which the effects in hydrocarbon compounds C_nH_{2n+2} were investigated [11]. In the region from n = 2 to n = 2000 (polyethylene) these effects depend only slightly on the length of the molecular chain in

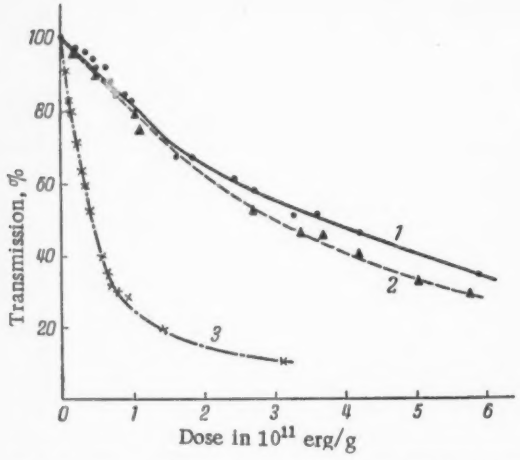

Fig. 1. Transmission of the light of the luminescence as a function of dose in irradiation by α-particles. 1) Plastic scintillator with 1.5% TPB; 2) plastic scintillator with 3% PT + 0.02% TPB; 3) plastic scintillator without additives.

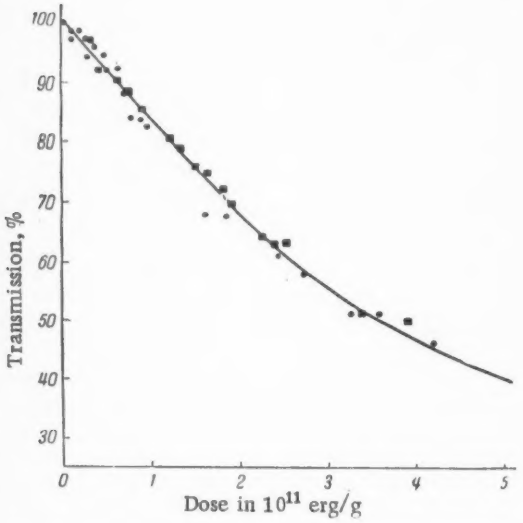

Fig. 2. Variation of transmission of plastic scintillator with 1.5% TPB for different intensities of irradiation by α-particles. ●) Dosage rate $3\,8 \cdot 10^8$ erg/g-hour; □) dosage rate $6.7 \cdot 10^8$ erg/g-hour.

the original material and the type of ionizing radiation. The effects of ionizing radiation on polystyrene, however, have not been given in nearly such great detail. It is known that under the influence of radiation lattice-like structures are formed in polystyrene, that is, cross links between the molecules. However, with the same radiation intensity this process in polystyrene occurs at a much slower rate than in polyethylene; 24 ev are required for the production of one cross link in polyethylene while 300-500 ev are required in polystyrene [12].

Another effect which occurs in the irradiation of most plastic and crystal scintillators, for example, anthracene, is the fact that material becomes yellow, cinnamon-colored or even black. The discoloration of the scintillator leads, naturally, to a reduction of the light yield and hence should be taken into account in measuring luminescence. Since this effect was of most interest from the point of view of measuring the emission of plastic scintillators, in studying the discoloration a method was used which made it possible to observe most directly the transmission of the luminescence emission as a function of irradiation of the sample. A sample, irradiated by different doses, was placed between the photomultiplier and a scintillator of the same composition as the sample; the scintillator was irradiated by β-radiation; this scheme made it possible to determine the transmission of the samples as a function of radiation dose, taking the transmission of the nonirradiated sample as 100%.

In Fig. 1 are shown the results of these measurements in pure polystyrene and in polystyrene with additives. It is obvious that in all three materials the transmission is reduced as the dose is increased and of these the pure polystyrene is affected most. Since the main component of the pure polystyrene luminescence lies in the region 3100-3700 A (according to [9, 13]) and in luminescence of polystyrene with the additives which were used, this radiation lies in the region 4200-5000 A, it follows from the data in Fig. 1 that the discoloration process is characterized by the production of some material which absorbs ultraviolet radiation more than visible light. This finding was verified by measurements of the absorption spectra in irradiated and nonirradiated samples.

In Fig. 2 are shown certain data from experiments which were performed to determine whether or not the observed reduction of light transmission with increased dosage depends on dosage rate. It is apparent that in the region which was investigated no such dependence was found; this is in accordance with the data in [14] concerning certain other radiation effects.

It is interesting to note the following two facts. First of all, the transmission of luminescence light in the scintillator with the TPB sample and pure polystyrene showed only a slightly different dependence on dosage than that in a plastic scintillator with an additive which has received an equal radiation dose. Hence, it is reasonable to assume that the reduction of transmission in all cases is due mainly to damage of the polystyrene molecule. Secondly, the transmission for plastic scintillators with PT and TPB additives, as a function of received radiation

dose, follows a simple exponential law to a dose of $7.5 \cdot 10^{11}$ erg/g. At this dose, each 100 ev of energy is absorbed in $2.1 \cdot 10^{-22}$ g of plastic; this is considerably less than the average mass of the polystyrene molecule. The exponential dependence of transmission on dosage indicates that the number of absorption centers increases in proportion to the dose. This situation may occur either as a result of the high effective transfer of excitation energy from damaged molecules to nondamaged molecules with the subsequent damage of the latter or as a result of the rather small yield of the damage reaction. It has been established experimentally that for a dose of $5 \cdot 10^{11}$ erg/g the transmission of the luminescent light from the TPB in a plastic scintillator is reduced by a factor of e, that is, the absorption factor is approximately 110 cm^{-1}. Since the material produced as a result of radiation damage of polystyrene which is responsible for the light absorption may reasonably be assigned a molecular weight of the order of 100, the molar absorption factor for this material should be no less than 150 l/mole·cm; this figure is certainly permissible but the yield of the damage reaction g cannot exceed 0.6 molecules per 100 ev.

Finally, we carried out a comparison of the reduction of light transmission of luminescence for plastic scintillators containing 1.5% TPB under irradiation by α- and β-particles. It was shown that the effect of α-radiation is approximately 8 times greater than the effect due to β-radiation as is frequently the case in small yield reactions.

Variation of Luminescent Yield. The investigation of the variation of light yield of plastic scintillators under irradiation was carried out with samples of pure polystyrene and polystyrene with an PT additive (2.5 and 3%) and TPB additive (from 0.01 to 0.12%) for single TPB (1.5%). As a typical example of many measurements which were carried out, in Fig. 3 are shown the results of one series of experiments with α-irradiation of three types of plastic scintillators, in Fig. 4 a comparison of the effect of α- and β-radiation for one type of plastic. In these figures all values of the light output were measured with luminescence excited by the same radiation to which the sample had been exposed. To determine the relative luminescent yield corrections were introduced for self-absorption. A knowledge of the spectral sensitivity of the photomultiplier is not required since the emission spectrum shows virtually no change.

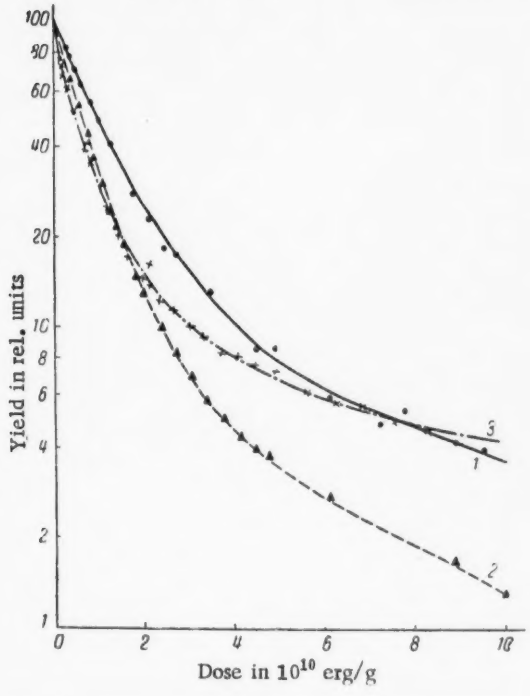

Fig. 3. Luminescent yield as a function of dose of α-radiation obtained by the scintillator. 1) Plastic scintillator with 1.5% TPB; 2) plastic scintillator with 3% PT + 0.02% TPB; 3) plastic scintillator without additives.

By itself the data on the change in transmission are not sufficient for introducing corrections since the emission centers are located at various depths of the excited layer of the plastic scintillator. It was established by experimental means that under the conditions of the present measurements (small sample diameter, large distance from the sample to the photocathode of the photomultiplier with no light pipe and dull sample surface) that the light which undergoes multiple scattering in the scintillator does not reach the photomultiplier. Hence, from the measured transmission and the known distribution of the intensity of the exciting radiation over the thickness of the plastic scintillators it is easy to calculate, to a good approximation, the corrections which are of interest.

It is apparent from these data that as the radiation dose is increased, the luminescent yield falls off (Fig. 3) and for equal doses of α- and β-radiation the reduction is more pronounced when the sample is irradiated by α-particles (Fig. 4). However, the damage effects of α-radiation in plastic scintillators are considerably less than in organic single crystals (see table) and the difference in the effects of α- and β-radiation are not so pronounced as in the case of anthracene [4]. The data from experiments in which two types of plastic scintillators were irradiated by α-particles (Fig. 5) indicate that in the intensity region which was investigated the damage is independent of dose rate, in contrast to anthracene single crystals [15] in which the damage calculated for identical doses is found to be greater at smaller dosage rates.

Dose of α-Radiation Producing 50% Damage of Organic Scintillators

Scintillator	Dose in 10^8 erg/cm^3
Single crystals [4]	
Anthracene	1.3
Naphthalene	1.7
n-Terphenyl	5.5
Stilbene	7.0
Pyrene	13
Toluene	32
Plastics	
Pure polystyrene	50
Polystyrene with 3% PT and 0.02% TPB	60
Polystyrene with 1.5% TPB	90

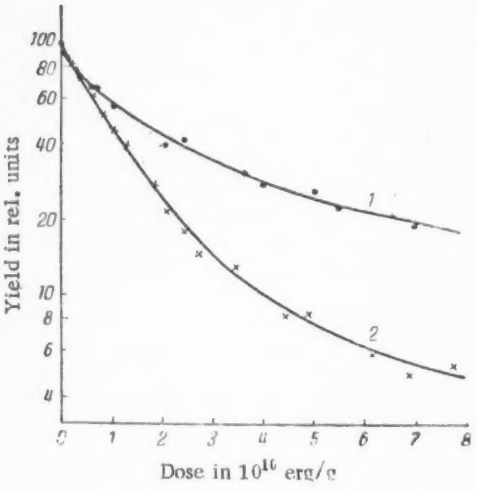

Fig. 4. Luminescent yield of plastic scintillators with 1.5% TPB as a function of radiation dose. 1) β-Radiation from $Ce^{144}-Pr^{144}$; 2) α-radiation from Po^{210}.

In Figs. 3-5 all initial values of the light emission have been taken as 100, so that no idea as to the absolute light yield of different plastic scintillators nor of the ratio of these yields can be obtained. These curves show the reduction of luminescent yield as a function of dosage; the nature of this reduction is different for different plastic scintillators and cannot be given by a simple mathematical expression. In irradiation by α-particles, the initial parts of the curves (approximately to 80% damage) are given by an exponential relation; however, there is a strong departure at high doses (Fig. 3). As a very rough approximation the complete curve may be given in terms of a sum of two exponentials. Plastic scintillators which contain luminescent additives do not follow the formula suggested for organic single crystals [16] having the form $1/(1 + kD)$, where D is the magnitude of the dose and k is a factor which is independent of D (Fig. 6). In β-radiation the curve showing the reduction of luminescent output shows an earlier departure from the exponential dependence than in α-radiation.

In order to obtain additional information on the damage process in plastic scintillators it is desirable to analyze quantitatively the reduction of luminescent yield at the beginning of irradiation. From the curves given in Fig. 3, it follows that doses sufficient for reduction of yield by a factor of e, (D_e) in all three types of plastic scintillators are almost the same and have a value of the order of 10^{10} erg/g. For plastic scintillators with additives of 2.5% PT + 0.01-0.12% TPB the size of the dose (within 10%) is independent of the concentration of TPB and is almost the same as that indicated above. It is easily shown that the dose D_e for the plastic scintillators used here corresponds to an average absorption of the energy of the ionizing radiation per molecule of the additive of approximately 320 ev, for plastic scintillators with 1.5% TPB and 70 ev for plastic scintillators with 3 or 2.5% PT + TPB. If it is assumed that the energy of ionization for α-particles in organic material is 35 ev, then for a dose D_e, one ionization event occurs on the average for $5 \cdot 10^{-21}$ g of material of the scintillator, that is to say, the average distance between ionization sites is approximately 20 A. In other words, in a volume of plastic scintillator containing, for example, one molecule of TPB, using a dose D_e there occurs on the average 9 ionization events (320 ev).

Since this amount of energy is very large as compared with the binding energy of the molecules being considered, and the average distance between ionization events is small, it may be assumed, particularly in regard to the exponential decay of luminescent yield at the beginning of the damage process, that the reduction of the light yield is explained by a reduction of the number of nondamaged molecules of the additive material (PT or TPB). Furthermore, it is well known that in such molecules with conjugated double bonds and benzene rings that even large amounts of excitation energy are very rapidly distributed over the many degrees of freedom without causing dissociation of the molecule. However, this assumption is not in complete agreement with the dependence of the magnitude of the scintillation of the plastic scintillators on concentration of luminescent additives found in [7]. The data presented in Fig. 7 lead to this same conclusion. A plastic scintillator with TPB was irradiated by β-particlaes from $Ce^{144}-Pr^{144}$. As the dose was increased the luminescence in this scintillator was excited by the same β-radiation, α-radiation from Po^{210}, and monochromatic ultraviolet radiation at wavelengths of 2537 and

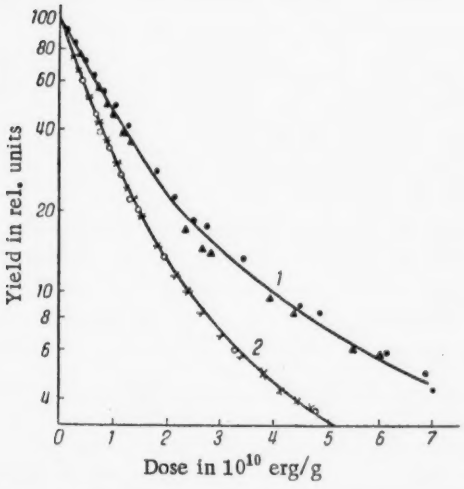

Fig.5. Luminescent yield of different plastic scintillators as a function of dosage of α-radiation at different dosage rates. 1) Plastic scintillator with 1.5% TPB: ●) $38 \cdot 10^8$ erg/g-hour; △) $6.7 \cdot 10^8$ erg/g-hour; 2) plastic scintillators with 3% PT + 0.02% TPB: x) $38 \cdot 10^8$ erg/g-hour, ○) $6.7 \cdot 10^8$ erg/g-hour.

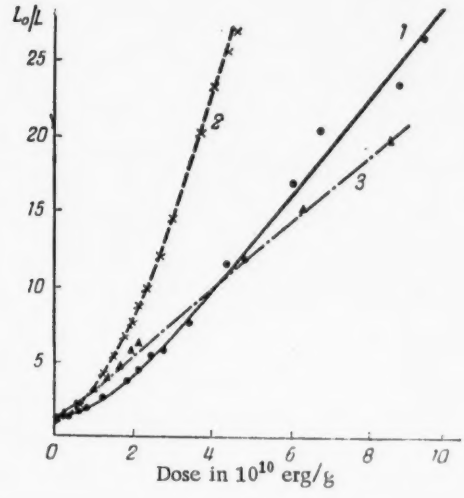

Fig. 6. Comparison of experimental data on luminescent yield for 3 plastic scintillators with the formula $L_0/L = 1 + kD$. 1) Plastic scintillator with 1.5% TPB; 2) plastic scintillator with 3% PT + 0.02% TPB; 3) plastic scintillator without additives.

3663 A. It is easily seen that the luminescent yield for excitation by ultraviolet radiation at a wavelength 3663 A falls off considerably slower than the yield associated with excitation by ionizing radiation. Since the long-wave ultraviolet radiation excites luminescence by direct absorption in the TPB molecule and is not absorbed by polystyrene, the different dependence of the luminescent yield on dosage indicates that, in itself, the damage of the TPB is not sufficient to explain the reduction in light output. It should be noted that these differences cannot be attributed to different depths of penetration of the exciting radiation; this depth is approximately the same for ultraviolet radiation and α-particles while for α-particles and β-particles it is considerably different, although in the latter case the initial parts of the curves in Fig. 7 are the same.

Thus, it is found that the damage of the TPB molecule cannot in itself explain fully the reduction in luminescent yield of plastic scintillators under excitation by ionizing radiation. It is undoubtedly true that a more important role is played by the damage of the basic component of the plastic scintillator–polystyrene. In this regard, in contrast to single crystals (for example, anthracene) it may be assumed that the irradiation of polystyrene by doses of the order of 10^{10} erg/g leads not only to the formation of materials which quench the TPB luminescence but is also accompanied by effects due to the high probability for the direct conversion of excitation energy into heat. Quantitative calculations indicate that using a reasonable choice of the parameters which characterize the radiation damage process it is possible to obtain satisfactory agreement with this pattern of experimental findings although the scheme which is used is not unique. Hence, it is not meaningful to evaluate all these possibilities in detail. It is obvious, that before an adequate solution of the question is obtained further investigations of the chemical damage processes, the reactions at the surface of the plastic scintillators and the physicochemical properties of the products of radiation damage will be required.

CONCLUSIONS

On the basis of the experimental results which have been presented the following conclusions as to the effects of ionizing radiation on plastic scintillators may be drawn:

the luminescent yield of plastic scintillators is reduced as the dose of radiation is increased;

the reduction of output occurs (in varying degree) for excitation of luminescence both by ionizing as well as long-wave ultraviolet radiation;

for the same absorbed dose the degree of damage of plastic scintillators due to α-radiation is greater than for β-radiation;

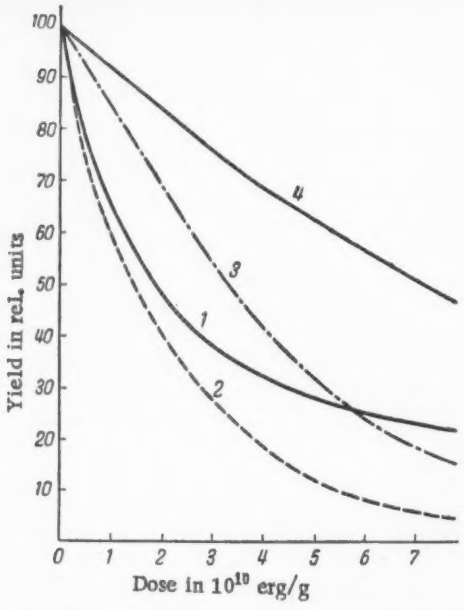

Fig. 7. The reduction of luminescent yield of plastic scintillators (with 1.5% TPB) for different doses of β-radiation as a function of the type of exciting radiation. 1) β-radiation from $Ce^{144}-Pr^{144}$; 2) α-radiation from Po^{210}; 3) ultraviolet radiation at a wavelength 2537 A; 4) ultraviolet radiation at a wavelength 3663 A.

for the same absorbed dose the degree of damage is independent of the dosage rate (in the range which was investigated);

in addition to the reduction of light output there occurs a reduction in the transmission of the light of the natural luminescence, which, however, is not sufficient to explain the reduction in the intensity of luminescent emission which is observed;

the transmission curves and the spectrophotometric measurements indicate that in irradiation of plastic scintillators, materials are formed which absorb strong ultraviolet radiation, in particular, in the region of luminescence of pure polystyrene;

the general behavior of the damage curves as a function of dosage cannot be described by any simple law. In the initial part the reduction of luminescent yield of pure polystyrene goes in accordance with the formula $1/(1 + kD)$, but in plastic scintillators of polystyrene with TPB or PT + TBP the luminescence follows an expression of the type $(-kD)$;

the reduction of the luminescent yield of plastic scintillators by a factor of e is produced by the dose of α-radiation of approximately 10^{10} erg/g which is approximately 50 times greater than the corresponding dose for an anthracene single crystal.

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SCIENTISTS OF OUR COUNTRY

CHEMICAL CHAIN REACTIONS AND COMBUSTION AND EXPLOSION PROCESSES

N. M. Emanuel

(On the award of the Nobel Prize to Academician N. N. Semenov)

Academician Nikolai Nikolaevich Semenov was awarded a Nobel Prize by the Swedish Academy of Sciences in October 1956 for outstanding work on the mechanisms of chemical reactions.

N. N. Semenov's discovery of branched chain reactions in chemsitry (especially chain combustion effects), his creation of a general theory of chain reactions and of thermal explosion, and his determination of the relationships between combustion, explosion, flame propagation, and the course of the combustion reaction, rapidly became known and accepted universally.

In 1931, the Institute of Chemical Physics of the Academy of Sciences USSR was established for the study and development of N. N. Semenov's new ideas; many fundamental investigations of chain reactions and combustion processes and explosions, which are most important fields of modern science and technology, were carried out in its laboratories.

It is hardly possible to name any other modern scientific concept which enjoys such popularity as the concept of chain reactions. It involves the idea of self-developing, self-sustaining and very rapidly growing chemical and physical processes in which small influences on a system lead to considerable changes in it. There is no doubt that the extraordinary popularity of chain reactions has been favored in no small measure by the discovery of the chain mechanism of the fission of uranium and plutonium atomic nuclei, which has made it possible to utilize the enormous sotre of energy in the atomic nucleus.

However, long before this discovery the branched chain mechanism of chemical processes was most thoroughly studied by N. N. Semenov, his pupils and associates.

Exactly 30 years ago, in 1926, N. N. Semenov and his associates, working in the Laboratory of Electronic Phenomena of the Leningrad Physico-Technical Institute, discovered and made a detailed study of a number of remarkable effects accompanying the reaction between phosphorus vapor and oxygen. It was noticed that when oxygen is admitted into a vessel containing phosphorus vapor, chemiluminescence of the oxidizing phosphorus begins not instantaneously, but only when a certain "critical" oxygen pressure is reached. There appears to be a kind of "lower limit" of pressure for the flame reaction. Below this limit, practically no reaction occurs in this system. Above the limit the reaction develops turbulently until a flame reaction begins. It was also noticed that the limiting pressure depends on the reactor diameter. It is higher in vessels of small diameter than in vessels of large diameter. Moreover, there is a certain "critical size" (diameter) for a system; below this the reaction cannot accelerate itself to an explosive rate. N. N. Semenov gave the following explanation for this peculiar behavior of chemical systems (abrupt transition from practically total inertness to a turbulently developing process). Highly reactive active centers – free atoms or molecular fragments (radicals) – occasionally originate in the system. These active centers are capable of reacting readily (with small activation energies) with molecules of the original substances to give the final reaction product while producing one or occasionally several new active centers. Each of these new active centers again reacts with a molecule of the starting substance, giving the final product and new active centers. In this way chemical reaction chains are produced.

Academician Nikolai Nikolaevich Semenov.

Before N. N. Semenov's work the idea of reaction chains which could originate in some cases under the action of light on chemical systems existed in chemistry in a very imperfect form. This idea was needed in 1913 by the German physical chemist Bodenstein to explain the very high quantum yield in the reaction of HCl formation from hydrogen and chlorine. It was assumed, however, that when an active center reacts with a molecule only one new active center is formed. Since active centers are lost from time to time and the reaction chains terminate, continuous intiation of the chains must be ensured. If chain initiation ceases, the chain process it elf dies down rapidly. The situation is different when, according to N. N. Semenov, the reaction of one active center may from time to time lead to the formation of more than one new active center, for example, three. One of these centers will then continue the chain initiated previously, while the others will initiate new chains, so that a kind of chain branching occurs. Naturally, these new chains will also branch, and therefore if the number of such branchings exceeds the number of chain terminations the reaction will be rapidly autoaccelerated to very high explosive velocities. This is the mechanism of chain combustion, clearly formulated by N. N. Semenov in his now classic paper "The Theory of Combustion Processes" (1928). The general nature of this mechanism was soon confirmed for many other chemical flame reactions, and N. N. Semenov created a strict quantitative theory of chemical branched chain reactions.

It is easy to see that the idea of a "critical diameter" in branched chain chemical reactions completely corresponds to the idea of "critical reactor size" in nuclear physics.

In addition to the possibility of chain branching, among other important points in this theory was the idea of chain termination (loss of atoms and radicals) at the walls of the reaction vessel and within the reaction mixture. It became clear that at low pressures the active centers can easily reach the walls of the vessel and are lost there, the rapidly developing reaction chain cannot take place, and the process is practically at a standstill, the system remaining apparently quite inert. As thepressure increases, access of the active centers to the walls of the vessel becomes more difficult, the number of reactions within the bulk of the system increases, and in suitable conditions the number of chain branchings exceeds the number of terminations, leading to a flame reaction. The "critical diameter" may be interpreted analogously. The greater is the diameter of the vessle, the higher is the probability that the number of branchings will exceed the number of chain terminations.

In a general theoretical paper published in 1943, N. N. Semenov gave special consideration to the question of chain termination both on the walls of the vessel and at various solid surfaces introduced into the reaction zone.

A few years later, in 1946, an interesting experimental study was carried out in the Institute of Chemical Physics on the influence of metal rods (of stainless steel, tungsten, platinum, graphite, etc.) on the lower limit of the chain flame reaction of hydrogen. Considerable addition chain termination takes place at such rod surfaces, and therefore the lower flame limit is raised considerably. An interesting experiment was performed – into a vessel containing a rod (for example, of graphite) a combustible gas mixture was admitted at a pressure above the lower limit for the vessel with the rod. The mixture caught fire, but rapid chain termination at the rod resulted in incomplete combustion. Therefore when the rod was withdrawn from the vessel, another flash of the unburnt gas occurred. This experiment was quite analogous to the regulation of the performance of nuclear reactors by means of regulating rods.

The above-mentioned concept of chain termination within the reaction mixture involves the assumption of reactions in which "capture" of active centers by other molecules takes place, with formation of inactive radicals, incapable of continuing the chains. Such processes usually require triple collisions (one active center and two molecules) and therefore the probability of loss of active centers within the mixture increases with pressure. In consequence, many flame chain reactions have, in addition to a "lower limit" caused by chain termination at the walls of the reaction vessel, also an "upper limit" caused by chain termination within the bulk. Above this limit the number of chain terminations again exceeds the number of branchings and the reaction rate diminishes rapidly.

The concept of chain termination within the volume was also advanced by the noted English physical chemist C. N. Hinshelwood, who was awarded the Nobel Prize for chemistry jointly with N. N. Semenov in 1956.

The loss of free atoms and radicals, which causes chain termination in chemical reactions, is completely analogous to neutron losses in nuclear chain reactions by leakage (escape of neutrons from the system), by resonance capture without fission, and also by parasitic capture (by the moderator, constructional materials, heat transfer medium, fission products, and impurities).

As the result of numerous investigations carried out at the Insitutute of Chemical Physics it was shown that chain reactions are widespread in chemistry. N. N. Semenov advanced general theories for unbranched and branched chain reactions, and provided them with a sound experimental basis. Extensive theoretical and experimental material on chain reactions, critically examined by N. N. Semenov in the light of these theories, was incorporated by him in his well-known monograph "Chain Reactions" (1934). Since that time all the development of research into chemical chain reactions all over the world was decisively guided by N. N. Semenov's ideas and theories advanced in this book.

It is interesting to note that, just as it is possible to obtain prolonged operation of a nuclear reactor as well as explosive nuclear fission, so in branched chain chemical processes slowly developing nonstationary processes can exist as well as thermal explosions. These are termed chain reactions with "degenerated" branching ("degenerated explosion"). In reactions of the "degenerated explosion" type the branchings are "delayed" and occur very rarely because some molecules of the intermediate substances formed in the chain reaction only rarely break up into free radicals. As the result of this mechanism the average life of an active particle is, in a sense, greatly lengthened and the reaction itself is extended in time, and becomes slower. Classic examples of slow branched chain processes are reactions of oxidation or organic substances. In such cases degenerated branchings are usually associated with breakdown of intermediate peroxides into free radicals which give rise to new oxidation chains. Although such a process is nonstationary, very often it develops extremely slowly (for example, sometimes over tens of hours in the oxidation of liquid hydrocarbons).

It is necessary to stress yet again the analogy between the slow development of a chemical chain reaction with degenerated branching and the operation of a nuclear reactor. It is well known that the relative ease with which a nuclear reactor can be controlled is due to the existence of delayed neutrons. The average life of a neutron is considerably increased because of the presence of delayed together with prompt neutrons. Because of this, although the rate of growth of the number of neutrons in the reactor obeys the laws for a branched chain process, it is nevertheless such that the reactor performance – neutron flux and power level – can be regulated.

N. N. Semenov also advanced the theory of chain interaction, which provided explanations of many effects due to mutual interaction of active centers. The readers of "Atomic Energy" need not be reminded of the well-

known ideas of the development of nuclear chain processes. However, no one who was familar with N. N. Semenov's theories of chemical chain processes before the discovery of these remarkable phenomena of nuclear physics can cease to marvel at the extraordinary clarity of N. N. Semenov's views on branched chain processes and their remarkable characteristics.

One of the most important problems in the field of chemical chain reactions is the problem of identification of active centers. Numerous investigations have been carried out in the Institute of Chemical Physics of the Academy of Sciences USSR to establish the actual chemical mechanisms of various chain reactions. Various physical and physicochemical experimental methods were used – mass spectrometry, spectroscopy, paramagnetic electron and nuclear resonance, photochemistry, radiation chemistry, labeled atoms, and many others.

New ideas and concepts of the mechanism of chemical processes in general and chain reactions in particular were recently reviewed by N. N. Semenov in his monograph "Certain Problems of Chemical Kinetics and Reactivity" (1954). Many important processes in chemistry have chain mechanisms.

Halogenation processes of organic compounds (in praticular, hydrocarbons) are examples of unbranched chain reactions. Hydrocarbon chlorination yields valuable organic solvents, economic poisons, medical preparations, refrigerants, and fire-extinguishing materials.

Oxidation processes of organic substances, including hydrocarbons, which yield valuable oxygen-containing products – synthetic fatty acids, alcohols, ketones, aldehydes, peroxides – are slow branched chain reactions.

The synthetic rubber, plastics, and synthetic fiber industries are based on chain polymerization reactions. Cracking, which is used for the production of gasolines, is also a chain process. Thus the chain theory of chemical processes forms the scientific basis of highly important chemical industries. Wise utilization of the principles of the chain theory makes it possible to intensify existing processes and to devise new rational methods for bringing about chemical reactions.

A new field of chemical processes, in which chemical chain and nuclear chain processes are closely interwoven, is worthy of attention; this is the field of radiation chemistry. Penetrating radiation, which inevitably accompanies the operation of nuclear reactors, may and should become one of the most effective means for initiation of chemical chain reactions, since the action of ionizing radiation ultimately reduces to the formation of free atoms and radicals in the chemical system. It is therefore not surprising that ionizing radiations are already being widely used in polymerization processes, for initiation of chlorination processes, and in many other instances.

A new interesting aspect of the use of the action of ionizing radiations was recently examined at the Insittute of Chemical Physics of the Academy of Sciences USSR. A remarkable feature of the branched chain mechanism was examined, whereby slow nonstationary chain processes can be stimulated not by constant action, but only by a brief action at the initial period of the process. It is necessary only to "give a push" to a branched chain reaction, after which the process must develop, with autoacceleration by means of the internal possibilities of the chemically reacting system, and by chain branching. It was found that the action of ionizing radiations can be used as such a brief stimulating action. This was confirmed by experiments on slow branched chain reactions of the oxidation of organic compounds. The possibility is not excluded that in a number of cases radiochemical stimulation of reactions will replace various catalytic methods for stimulation of slow oxidation processes, which complicate the chemical system.

There is no doubt that the numerous peculiarities and remarkable properties of chemical chain reactions will make it possible in the near future to make new suggestions for the use of the effects of penetrating radiations, thus opening up more and more possibilities for the peaceful use of atomic energy.

It is interesting to note that chain mechanisms are probably not confined to chemical and nuclear reactions. In all probability many biological processes are effected by chain mechanisms.

However, despite the fact that chain reactions are widespread in chemistry, this is by no means the only mechanism. It is well known that chemical reactions can also occur directly between molecules of the reactants, with participation of ions, and by a radical mechanism but without chain formation.

Similarly, the explosive course of chemical reactions cannot be regarded as specific for branched chain reactions only. N. N. Semenov's publication "The Theory of Combustion Processes," which has already been

mentioned, contains a quantitative theory of thermal explosions which may occur, under suitable conditions, in all exothermic processes irrespective of the mechanism of the reaction in which energy is liberated. In such cases the cause of the explosive course of the process is progressive heat evolution in the reaction, which in certain conditions can exceed the loss of heat from the system, thus heating the reaction mixutre and rapidly accelerating the reaction. A thermal explosion in a chemical system is quite analogous to a thermonuclear explosion in its mechanism and laws governing it.

This analogy becomes even more complete if it is remembered that typical thermal explosion effects are found in chemical reactions which, in addition to high heat effects, also have high activation energies, so that they can commence only after considerable heat has been supplied. The explosions then occur abruptly, otherwise the reaction begins to proceed at a high rate even in stationary conditions and the typical explosive character is lost. It is clear that typical explosion conditions apply to a thermonuclear explosion. In contrast to thermal chemical reactions, with activation energies of the order of a few electron volts., the activation energy for a thermonuclear reaction is millions of electron volts. Therefore temperatures of the order of tens of millions of degrees are necessary to bring about thermonuclear processes. In other words, the condition for a thermal explosion, a high thermal stability of the system, is completely fulfilled in thermonuclear reactions. Another condition is satisfied at the same time – the evolution of considerable amounts of energy in the reaction.

The theories of thermal spontaneous ignition, flame propagation, detonation, and turbulent combustion have been developed in detail at the Institute of Chemical Physics. These theories are of great assistance in the solution of various practical problems of the utilization of combustion and explosion processes. Soviet physicists and physical chemists know N. N. Semenov well as a scientist of exceptionally high creative potential with the gift of broad and clear generalization coupled with extreme clarity of concrete ideas. These features, which characterize the scientific activity of N. N. Semenov, have enabled him to create brilliant theories in important fields of modern science and technology and to establish a leading scientific school of thought.

The inner contents of N. N. Semenov's theories go far beyond the limits of chemistry and rise to the level of general laws for the development of many natural processes.

LETTERS TO THE EDITOR

TRUE ELECTRONIC SPECTRA IN IONIZATION CHAMBERS

K. K. Aglintsev, V. V. Mitrofanov and V. V. Smirnov

Measurements of radiation levels in fields of β or γ radiation are generally carried out with ionization chambers or various instruments which are calibrated against ionization chambers. In practical γ-ray dosimetry thimble or wall chambers are generally used; the ionization of the gas in these chambers is due, almost exclusively, to electrons which are ejected from the walls of the chamber upon the absorption of γ-rays.

The relation between the ionization of the gas in the chamber and the energy of the radiation absorbed in the wall, according to the Bragg-Gray theory [1, 2], is given by

$$Q = \frac{\Delta E}{s\,\epsilon}, \qquad (1)$$

where Q is the number of ion-pairs produced in 1 cm^3 of the gas in the chamber; ΔE is the energy of the radiation absorbed in 1 cm^3 of the wall material; $\underline{s}$ is the ratio of the stopping power of the wall material to that of the gas and ϵ is the ionization potential.

Equation (1) is valid experimentally to a high degree of accuracy in the ideal case, when the following conditions are fulfilled:

a) the volume occupied by the gas can be considered as a small space in the wall material;

b) the atomic numbers of the wall material and and the gas are almost the same;

c) the radiation field can be considered uniform at all points in the chamber.

In practice, these conditions are not completely fulfilled and the application of the Bragg-Gray theory may lead to certain errors which, however, cannot be estimated from the theory.

An accurate analysis of the operation of the chamber and the valid application of Eq. (1) are possible only in those cases in which the energy and direction distributions of the electrons which are ejected from the chamber walls are known in detail. Theoretical results have been worked out by Spencer [3] who considered several particular cases; in general, however, there are no experimental data on the electronic spectra. Hine [4] has presented the results of measurements in which

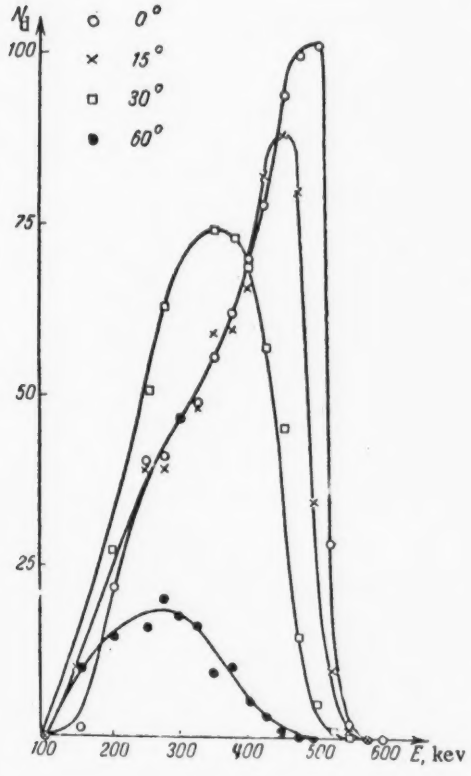

Fig. 1. Spectra for electrons emitted from a target by γ-rays from Cs^{137} at angles 0°, 15°, 30°, and 60°

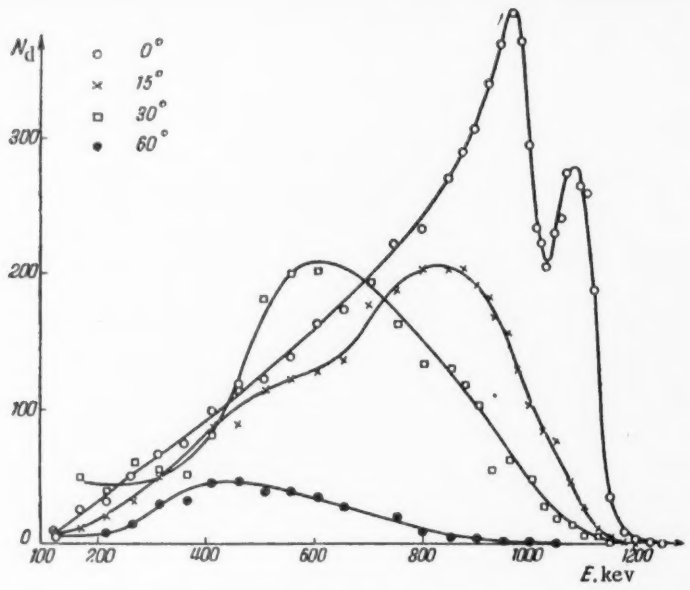

Fig. 2. Spectra for electrons emitted from a target by γ-rays from Co^{60} at angles of 0°, 15°, 30° and 60°.

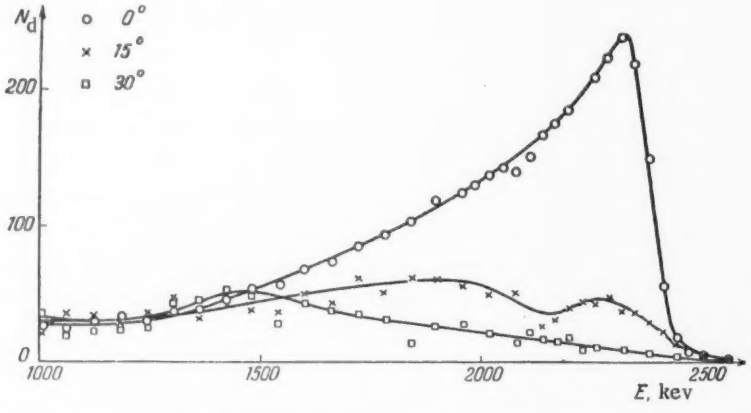

Fig. 3. Spectrum of electrons emitted from a target by γ-rays from RaTh at angles of 0°, 15°, and 30°.

estimates were made of the fraction of electrons from the "front" and "back" walls of the chamber in the total ionization current.

We have undertaken a systematic investigation of electronic spectra in ionization chambers and counting tubes. This experimental study of the spectra of electrons, ejected by γ-rays of various energies and at different angles, from a target similar to the walls of an ionization chamber was carried out with a magnetic spectrometer operated on the principle of the "ritron" [5].

To study the angular distribution of the electrons, a plexiglas target 3.5 mm thick and a γ-ray source were rotated through the appropriate angles about a vertical axis passing through the center of the target. The γ-ray

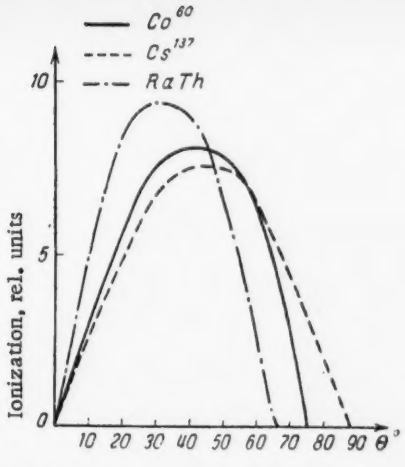

Fig. 4. Ionization activity of electrons emitted from a target by γ-rays from Cs^{137}, Co^{60}, RaTh at various angles.

source was inside a lead collimator within the spectrometer chamber.

The spectrometer construction and the collimator system made it possible to study the electronic spectra at angles of 0°, 15°, 30°, 60°, 90°, and 180°. The following radioactive isotopes were used as γ radiation sources: Co^{60} ($h\nu$ = 1.17 and 1.33 Mev), Cs^{137} ($h\nu$ = = 0.663 Mev) and RaTh ($h\nu$ = 0,57 and 2.26 Mev).

In Figs. 1 and 2 are shown the spectra of electrons ejected from the target at angles of 0°, 15°, 30° and 60° which were obtained for equal values of the solid angle for the Cs^{137} and Co^{60} sources in the energy region from 100-1200 kev. In Fig. 3 are shown similar curves taken with the RaTh source in the energy region from 1000-2600 kev for electron ejection angles of 0°, 15°, and 30°. At the other angles, the effect was so weak that it was impossible to obtain curves.

Ionization in a plane slit ionization chamber, due to electrons with energies from E to E + dE emitted at angles from Θ to Θ + dΘ, in the case of an air-equivalent wall, will be proportional to the quantity $\frac{1}{\cos\Theta}\frac{dE}{dx}N(E, \Theta)\sin\Theta dE d\Theta$, where $\frac{dE}{dx}$ is the ionization loss for electrons in air, $\frac{1}{\cos\Theta}$ is the path length for electrons emitted at an angle Θ and N(E, Θ) are the experimentally determined values shown in Figs. 1-3. The factor $\sin\Theta$ takes into account the value of the solid angle.

In Fig. 4 is shown the ionization produced by electrons emitted at various angles. The value of the angle Θ is plotted along the abscissa axis and the quantity $\frac{1}{\cos\Theta}N(E, \Theta)\frac{dE}{dx}\sin\Theta$ is plotted along the ordinate axis.

Using these results it is an easy matter to plot the energy spectrum for the electrons and to obtain data for calculating the efficiency of chambers and counting tubes.

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INELASTIC INTERACTION OF 14-MEV NEUTRONS WITH NUCLEI*

V. I. Strizhak

The cross sections for inelastic interactions between 14-Mev neutrons and various nuclei have been measured. Some of the results of this work have been reported at the International Conference on the Peaceful Uses of Atomic Energy at Geneva [2].

The cross sections for inelastic interactions were measured in transmission experiments with threshold detectors, surrounded by a thin layer of the material being investigated.

The threshold detectors were the reactions $Cu^{63}(n, 2n)Cu^{62}$ and $Al^{27}(n, p)Mg^{27}$ with thresholds at 3 and 12.5 Mev and half-lives in Cu^{62} and Mg^{27} of 9.9 ± 0.1 and 10.25 ± 0.1 min, respectively. By using threshold detectors with different thresholds it was possible to make an estimate of the energy distribution of the scattered neutrons.

The detectors were long tapes, tapered at one end so that a spherically shaped object was obtained when the tapes were rolled up into coils.

In order to place them in front of the counter after irradiation, the tapes were removed on a mandrel in a cylinder.

All the scatterers, with the exception of iodine, mercury, and tungsten, were ground or cast. The mercury was poured into a thin-walled container, the iodine and the tungsten were pressed from fine crystals and powders and were also placed in thin-walled containers. When the iodine, barium, tungsten, and mercury were irradiated, the detector, after having been irradiated without the scatterer, was placed in the same container as the scatterer.

In all cases, the thickness of the scattering shell was not greater than 2 cm. Multiple scattering was not taken into account.

The measurements in aluminum, iron, and lead were carried out with scatterers of equal thickness (from 0.8 to 3 cm).

Since the scatterer and the detector were of finite dimensions, it was necessary to consider the attenuation of the neutron flux in the scatterer and the variation in path for elastically scattered neutrons in the scatterer and detector as well as the divergence of the neutron flux from the source.

The calculations relating to the experimental geometry have been carried out in [3, 4].

The neutrons were obtained from the reaction $T(d, n)He^4$ by bombarding a tritium-zirconium target with a beam of deuterons accelerated to 110 kev. A neutron generator was designed and constructed for this purpose. The accelerating tube and the vacuum system of the neutron generator were separated from the field by a distance of three meters, but the target chamber was fastened to a tube 100 cm in length, so that the minimum distance of the target from the field and walls was ~ 2 m. The ion beam was focused so as to cover the entire target (diameter 14 mm).

The measurements were carried out in the following manner. Two detectors (copper or aluminum) were placed at an angle of 90° to the deuteron beam at a distance of 28 cm from the target in standard receptacles, attached to a thin-walled ring and which could be moved with cables; these were alternately enclosed by the scatterer. After irradiation for a period of 10 min, the detectors were removed in cylinders and set up in front of the counters for a simultaneous count of the activities. The measurements consisted of cycles of four exposures.

* This work was carried out at the Institute of Physics, Acad. Sci. Ukranian S.S.R. in 1953-1954 [1].

Scatterer	Cross section for inelastic collisions in barns	
	Cu detector	Al detector
Carbon	0.63 ± 0.05	–
Magnesium	0.96 ± 0.08	0.7 ± 0.2
Aluminum	1.04 ± 0.06	–
Sulfur	1.08 ± 0.08	–
Iron	1.29 ± 0.07	1.0 ± 0.2
Nickel	1.38 ± 0.05	–
Copper	1.40 ± 0.05	–
Zinc	1.37 ± 0.07	1.2 ± 0.2
Selenium	1.57 ± 0.08	–
Cadmium	1.84 ± 0.06	–
Tin	1.81 ± 0.08	–
Antimony	1.87 ± 0.08	1.8 ± 0.3
Tellurium	2.00 ± 0.10	1.9 ± 0.3
Iodine	1.88 ± 0.16	–
Barium	1.90 ± 0.17	–
Tungsten	2.35 ± 0.14	–
Mercury	2.8 ± 0.3	–
Lead	2.42 ± 0.08	2.2 ± 0.3
Bismuth	2.40 ± 0.09	–

Two with the scatterers interchanged and two with the counters intechanged. The attenuation of the neutrons flux following passage through the scatterer was taken to be the average of the values obtained in this cycle.

Using this method it was not necessary to take into account the exposure time, the dead time, and the counting time. The results which were obtained are independent of the counter efficiency and fluctuations in the intensity of the neutron source.

The value of the cross section for inelastic interactions is obtained from the expression

$$\sigma_{in} = -\frac{1}{n\delta} \ln \frac{b}{a},$$

where n is the number of nuclei in 1 cm^3 of the scatterer; δ is the effective thickness of the scatterer in centimeters; b and a are the activities of the detectors irradiated with and without the scatterer.

In the table are shown the computed cross sections for inelastic scattering of 14-Mev neutrons.

The cross section for the inelastic interaction of neutrons with energies of 14 Mev, in contrast with the cross sections measured earlier for neutrons of lower energy, increases monotonically with the mass number of the scatterer and is approximately the same as the geometric cross section $\sigma = \pi(R + \lambda)^2$.

The results reported by other authors are found to be in good agreement with the present data [5-11].

The measurements with the aluminum detectors indicate once again that the majority of secondary neutrons [inelastically scattered and obtained as a result of the (n, 2n) reaction] have an energy less than 3 Mev.

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* T. p. = C. B. Translation pagination.

DETERMINATION OF TRITIUM CONTENT IN LIQUIDS

E. G. Gracheva and Sh. G. Khusainova

To determine the tritium content of liquid samples tritium is introduced into an ionization chamber as a component of a vapor or gas which is obtained by chemical decomposition. These methods have been described in the literature. *

If the liquid being analyzed contains no other radioactive elements beside the tritium, the measurements can be performed using the bremsstrahlung in the test material produced by the β-particles from the tritium.

In doing this it is sufficient to deposit a small layer of the liquid being analyzed in front of a thin-walled counter, the pulses of which can be recorded.

The measurements have shown that this method is capable of finding a tritium content of as little as 10^{-4} curies/liters in a few milliliters of water.

The measurements were made with end-counters with windows approximately 4 mg/cm^2 thick and 40 mm in diameter. The layer of water, the height of which was less than 1.5 cm, was poured into a beaker with an aluminum cover 18 μ thick which served to shield the apparatus from the loading due to the vapors.

The amount of tritium in the test was found by comparing the effect of the sample being tested on the counter with a liquid sample of known tritium content.

Received September 19, 1956

* V. Bochkarev, et al., Measurement of the Activity of β- and α-Sources (1953).

APPLICATION OF PLASTIC SCINTILLATORS IN DOSIMETRY MEASUREMENTS

I. M. Rosman and K. G. Zimmer

Organic luminescent materials have been found suitable for a number of dosimetry measurements [1, 2]. The high radiation stability of plastic scintillators (PS), mainly polystyrene [3], makes it possible to use these materials for measurements under conditions of high radiation dose.

The authors have undertaken an investigation directed toward finding any possible saturation effect, that is, to see whether or not the proportionality between the intensity of the scintillations from plastic scintillators and the radiation intensity is maintained. The appropriate experiments were performed exciting the plastic scintillators by α- and β-particles.

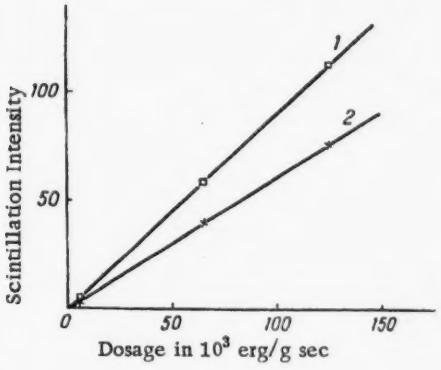

Fig. 1. Scintillation intensity from plastic scintillators as a function of dosage for β-radiation. The irradiation was carried out with preparations of Ce^{144}–Pr^{144} with a filter of approximately 11 mg/cm^2. 1) Curve obtained in a plastic scintillator containing paraterphenyl (3 percent by weight) and 1,1.4,4-tetraphenylbutadiene-1,3 in polystyrene (0.02 percent by weight); 2) curve obtained in plastic scintillator containing tetraphenylbutadiene (1.5 percent by weight).

Most of the work was with plastic scintillators of polystyrene with admixtures of tetraphenylbutadiene and paraterphenyl with tetraphenylbutadiene. The scintillation intensity was measured using the average current of a PEM-19 photomultiplier. The doses of α-radiation (Po^{210}) and β-radiation (Ce^{144}–Pr^{144}) were determined by the method described in [3]. In the figure is shown the relation between the scintillation intensity for both plastic scintillators as a function of the β-radiation dose. It is apparent that in the region which was studied (up to 10^5 erg/g sec) a strict proportionality is maintained between these quantities. It was also established that there were no saturation effects in the case of α-radiation (the highest dose was $\sim 10^6$ erg/g sec). The appropriate data are shown in the table.

TABLE

Scintillation Intensity of Plastic Scintillators as a Function of Radiation Dosage in Excitation by α-Particles from Po

Sample no.	Scintillation intensity, L (relative units)	Dose P in 10^3 erg/g sec	L/P
1	74.2	158	$47 \cdot 10^5$
2	100	206	$48 \cdot 10^5$
3	425	876	$48 \cdot 10^5$

Thus, it has been verified that the luminescent yield of plastic scintillators is proportional to the level of the ionizing radiation, at least up to 10^6 erg/g sec or 10^4 r-equiv/sec. Further, the results of studies on damage to plastic scintillators by ionizing radiation [3] indicate that for an accuracy of dosimetry measurements of the order of 10% it is possible to neglect damage effects (reduction of yield and addtional absorption of inherent luminescence up to a total dose of $3 \cdot 10^6$ r-equiv.

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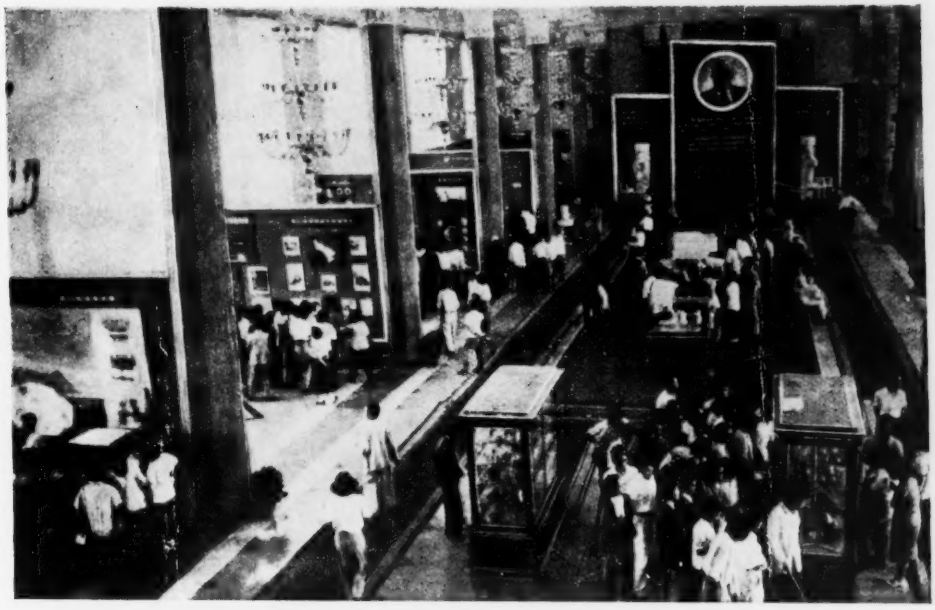
SCIENCE CHRONICLE

SOVIET EXPOSITION IN PEKING FOR PEACEFUL USES OF ATOMIC ENERGY

The Soviet scientific and technological exposition for peaceful uses of atomic energy closed after two months of operation in Peking on the 15th of August, 1956. During two months representatives of the most diverse laboring classes of the Chinese capital became acquainted with the achievements of the USSR in the field of peaceful uses of atomic energy. A great number of the visitors to the exposition came especially for it from other towns of the Chinese People's Republic. Among the more than two hundred thousand visitors at the exposition were workers and employees of business establishments and factories, students, workers in the fields of science, technology, medicine and agriculture, those in military service in the National-liberation army and others. It was a great honor for the Soviet organizers of the exposition that it was visited and thoroughly examined by the leaders of the Chinese Communist Party and by members of the Chinese National Republic government.



Peking: At the Soviet Exposition on the Peaceful Uses of Atomic Energy.

The exhibits displayed at the exposition – diagrams, plans, photographs, models, samples of all kinds of equipment and other materials presented in a graphic and accessible form – acquainted visitors with the tremendous reserves of energy locked within the atomic nucleus, with the methods of liberating this energy and harnessing it, with the grandiose perspectives which open up before the various branches of science and national economy in conjunction with the application of artificially radioactive isotopes. Here were displayed materials on the projected powerful atomic power stations in the Soviet Union, and atomic powered transportation. Methods

of applying tagged atoms and radioactive radiations in technology, agriculture and medicine were broadly demonstrated.

The exposition did not popularize these achievements solely through the use of exhibits. During all the time that the exposition was open, films were shown which dealt with questions concerning peaceful uses of atomic energy. Workers at the exposition gave dozens of reports on this subject before large audiences. Soviet and Chinese specialists wrote over 50 scientific and popular-scientific papers for the Chinese press on the subject of peaceful uses of atomic energy.

Acting upon the wishes of a number of Chinese organizations, the exposition provided, for a large group of Chinese specialists of diversified interests, a more thorough study of the materials exhibited. More than 8,000 specialists were included in this program.

Approximately 500 visitors at the exposition left their impressions. Noting the great success of Soviet science, these visitors at the exposition expresses their profound thanks to the Soviet people and government for their disinterested help to China.

The success of the exposition was due in many ways to the constant attention and interest given it by the government of the Chinese People's Republic, the Chinese Academy of Science, and other Chinese institutions and departments which provided the exposition with its indispensable quota of specialists, among them highest ranking scientists. These Chinese comrades, working with soviet specialists during the time that the exposition was open, gave to this communal project much time and labor. The exposition became an important event in the development of Soviet-Chinese scientific exchange. Its organization and execution represent one of the many demonstrations of brotherly friendship closely uniting the Chinese people and the peoples of the Soviet Union.

P. A. Cherenkov

THE FIRST SESSION OF THE SCIENTIFIC COUNCIL OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH

In accordance with the Agreement on the Organization of a Joint Institute for Nuclear Research concluded in Moscow, on the 26th of March, 1956 between the governments of eleven countries, an international scientific research organization was founded with the aim of providing joint theoretical and experimental research in the field of nuclear physics and the concurrence in the development of that science by the governments, members of the Institute. The basic principles of the organization of the Institute are well known from the already promulgated agreement.*

A meeting of the plenipotentiary delegates of the Institute Member Governments took place that year at the Institute from the 20th to the 23rd of September for the ratification of the Constitution which was prepared by the directors of the Institute. In the friendly discussion which followed, the final draft of the Constitution was thoroughly discussed and finally unanimously adopted.

The basic principles governing the work, organization and management of the Institute, which naturally evolved from the general sense of the Agreement on the Organization of the Institute and which are indispensable to its normal operation, were formulated in the Constitution.

As the full text of the Joint Institute Constitution is published separately in this number, we will not discuss these documents in detail. We mention only that, according to them, other governments who may want to take part in the work of the Institute and will declare themselves in agreement with its Constitution may become members of this international organization. In this way the Democratic Republic of Viet Nam was admitted as the 12th member of the Institute. The Constitution left to the Board of Directors of the Institute the right of deciding, in each individual case, bearing in mind the principle of reciprocity, the question of work in the Institute by scientists whose governments are not members of the Institute and also to determine by agreement with the interested government, the scientific institution, or the scientist himself, the extent and scope of compensation for the use of the facilities and materials of the Institute.

After the adoption and the signing of the Constitution on September 24th the first meeting of the Scientific Council of the Joint Institute took place; members of the Council having a decisive vote, other than the Director and two Vice-Directors of the Institute, include the following delegates of Member Governments: M. Prifti (People's Republic of Albania), G. Nashdakov and E. Dzhakov (People's Republic of Bulgaria), L. Yanoshi, K. Novobatsky, and Sh. Salai (People's Republic of Hungary), Le Van-Tkhien (Democratic Republic of Viet Nam), K. Rambush, G. Gerts, G. Barvikh (German Democratic Republic), Van Gan-Chan, Khu Nin, and Chzbao Chzhun-Zhao (Chinese People's Republic), Kim Khen Bon and Ten Gyn (Korean People's Democratic Republic), Sodnom Namsrain (Mongolian People's Republic), L. Infeld, A. Soltan, and G. Nevodnichanski (Polish People's Republic), Kh. Khulubei, Sh. Tsitseika, and V. Novaku (Rumanian People's Republic), V. I. Veksler, B. P. Dzhelenov and I. E. Tamm (USSR), Ch. Shimane and V. Petrzhilka (Czechoslovakian Republic).

Directors of Laboratories, if they are not appointed by their governments as members of the Scientific Council of the Institute, are included in its membership with the right of deliberative vote.

At the meeting of the Scientific Council the position of the Scientific Council of the Institute and Scientific Laboratory Councils was discussed and confirmed.

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* "Pravda" July 12, 1956.

Meeting of the Scientific Council of the Joint Institute for Nuclear Research.

Then candidates for Laboratory Directors presented by the Directors of the Institute were discussed and confirmed. The following were chosen by secret ballot: Director of High Energy Laboratory – V. I. Veksler; Director of Nuclear Problems Laboratory – V. P. Dzhelepov, Director of Theoretical Physics Laboratory – N. N. Bogolyubov. The Scientific Council likewise approved the candidature of I. M. Frank to the post of Director of the Neutron Physics Laboratory which is to be created within the Institute in the near future.

Furthermore the plans of the Scientific Laboratory Council for further Institute development for 1956-60 were approved.

Director of the Institute, D. I. Blokhintsev, suggested that the Scientific Council consider plans for supplementing the experimental equipment of the large 10-Bev synchrophasotron by the construction of a new wing with experimental equipment for work with photoplates and bubble chambers of various dimensions in impulse magnetic fields. It was suggested that a large liquid hydrogen chamber be built, a cryogenic plant put up and laboratory built for the production of photomaterials. To secure these electrical installations new energy plants must be constructed. Inasmuch as this equipment is necessary for the full use of scientific research possibilities on the world's largest proton accelerator, its construction becomes the most vital problem in the building program of the Institute.

The Scientific Council was then shown plans for an accelerator for highly ionized ions, construction of which, in accordance with the Agreement on the Organization of the Institute, had already begun on the grounds of the Nuclear Problems Laboratory. A high activity radiochemical laboratory will be built in connection with this accelerator. Also plans were developed and orders placed for the construction of a reactor with a high density neutron flux. The Scientific Council was informed of essential changes that had been made in this plan. It is assumed that the reactor will be operating on an impulse system. The reactor will serve as a base for the Neutron Physics Laboratory.

For the Theoretical Physics Laboratory it was suggested that a new building be erected with a large library and with equipment consisting of electronic high-speed calculating machines.

The Scientific Council heard with great interest of the plans suggested by the directors, and a lively discussion followed, during which many questions were clarified, remarks studied and certain legislative enactments adjusted. The Scientific Council approved of the projected plan of Institute development.

Further business of the day was the discussion and approval of the plans for scientific research projects of the Laboratories for 1957. The problems of the High Energy and Nuclear Problems Laboratories were thoroughly explained by the directors of these Laboratories, V. I. Veksler and B. P. Dzhelepov. These problems consider the possibility of basic installations. Therefore in the High Energy Laboratory the first place is given to research work on new particles, and at the Nuclear Problems Laboratory, exact quantitative study of the processes brought about by a polarized pulse of high energy nucleons.

Director of the Institute, D. I. Blokhintsev together with the author of this article presented plans for scientific research at the Neutron Physics and Theoretical Physics Laboratories. In the plans for the Neutron Physics Laboratory, work was projected in connection with the starting of the reactor and also on measurements in connection with pulses of monoenergetic neutrons. The plan of work for the Theoretical Physics Laboratory includes basic problems of contemporary theory of elementary particles and their interaction and also some special problems on the theory of the atomic nucleus.

The Scientific Council approved the projected plans of scientific research work for all four Institute Laboratories.

The Scientific Council gave close attention to the study of contingents of scientific workers who are to be sent to the Institute from other Member-Countries, outside of the USSR. There are new already more than 20 scientific coworkers from these countries working at the Institute and during 1957 their number will be considerably increased. There is no doubt that this will be of great help in the development of scientific research in the Institute as well as in the Member-Countries.

The examination of a series of questions concerning the organization of scientific research concluded with reports by the Vice-Director M. Danysh on the organization of general methodological works and Director of the Nuclear Problems Laboratory V. P. Dzhelepev on the project of creating at the Institute an experimental fac-

tory which could produce specialized physical apparatus not only for the Institute itself but for scientific research institutions of Member-Countries.

Last item on the agenda of the first meeting of the Scientific Council of the Joint Institute for Nuclear Research was the report of Professor V. A. Petukhov on the possibility of studying the scattering of electrons by electrons in energy levels close to the meson-formation threshold, with the help of a special accelerator using electron pulses. A lively discussion among the scientists present followed the report.

In closing the first session of the Scientific Council of the Joint Institute for Nuclear Research, the Council chairman, D. I. Blokhintsev remarked that the members of the Council showed great interest in questions of organization and work of the Institute. Scientists of many lands quickly got to know each other and came to unanimous conclusions, even though on some points they had differences of opinion. In conclusion D. I. Blokhintsev thanked the members of the Scientific Council for their hard and fruitful work carried out during the session.

After the meeting of the Scientific Council closed, the Director of the High Authority for the Utilization of Atomic Energy for the USSR Council of Ministers, E. P. Slavsky, congratulated all those present in the name of the Soviet government, on the completion of a fruitful first session of the Scientific Council of an international organization in the field of nuclear physics and wished similar fruitful production to the group which will be created at this Institute on the basis of decisions taken by the Scientific Council. This statement met with great satisfaction.

After the Scientific Council finished its work, the first meeting of the Finance Committee took place; the Committee confirmed the tentative budget presented by the Directors of the Institute for 1956-1957 and thus guaranteed the completion of plans for the development of the Institute and of scientific research problems approved by the Scientific Council.

The directors and coworkers of the Institute are now faced with the grave problem of realizing the hopes placed in them by the Member-Nations of the Joint Institute for Nuclear Research.

Vatslav Votruba

QUESTIONS OF MEDICAL RADIOLOGY BROUGHT UP AT THE ALL-UNION CONFERENCE OF PUBLIC HEALTH WORKERS

At the All-Union Conference of active public health workers held on the 25th and 26th of October, 1956 meetings of the medical radiology section were held. Reports given by a board member of the Ministry of Public Health of the USSR, A. I. Burnazyan, on "Conditions and Measures Taken for the Further Improvement of Work on Medical Radiology and Utilization of Radioactive Isotopes in Medicine" and by (an active member of the Academy of Medical Sciences in the USSR) Professor A. A. Letavet on "The Protection of Labor and Safety Measures Necessary for Work on Radioactive Isotopes and Radiations" were heard and discussed.

In the first report A. I. Burnazyan summarized the application of radioactive isotopes of cobalt, phosphorus, iodine, and gold in medical practice. He explained in detail the application of radioactive isotopes in the diagnosis and treatment of malignant growths, in diseases of the blood system, thyroid gland, and skin, and also showed how radioactive isotopes can be used in the study of basic medical science problems, as used in microbiology, physiology, pathophysiology, and pharmacology.

Considerable place was given in the report to the question of equipping medical institutions with radiation sources and radiometric apparatus. The speaker indicated that in the near future public health institutions would receive powerful radiation sources including neutron sources and betatrons, which will make it possible (with lesser injuries to skin coverings) to concentrate the main radioactive radiations dose directly on to the growths. This will improve the treatment of malignant growths of the digestive tract, lungs, and other organs.

The quantity of radioactive isotopes sent to clinics and institutions has increased approximately 40 times in comparison with 1949. Likewise there is a constant increase in the number of medical institutions doing scientific research in the field of medical radiology.

In order to carry out experimental work on biological effects of radiation the Ministry of Public Health has constructed within its system powerful sources of γ-radiation; EGO-1, an experimental γ-radiator (220 curies radioactive cobalt, giving 45 r/min) and EGO-2, 8500 γ-equivalent of radium giving off 630 r/min. Moreover in the near future there will be built a γ-installation for 32,000 gamma equivalents of radium, giving off 2500 r/min. During 1957 the electrotechnical industry will likewise set up, for public health use, a γ-apparatus with radioactive caesium Cs^{137} having a number of advantages over Co^{60}: longer half-life, less harsh radiation. All this brings forth the acute problem of training a cadre of radiologists. The number of radiology specialists trained recently does not satisfy the demands that have arisen. Likewise the situation is not good in the training of a middle class of medical personnel, those working on the measurement of radioactive radiations.

In conclusion the speaker presented in detail existing achievements in the field of treatment and prophylaxis of radiation sickness and discoveries made with the help of tagged atoms, which in the near future will help solve a series of theoretical and practical medical problems.

In the second report Professor A. A. Letavet pointed out the special role of sanitation training in giving a correct understanding of the effects of radioactive radiations. A. A. Letavet said that it was very important not only to maintain a constant control over public health organizations for the observance of established hygienic rules and norms when working with radioactive substances, but also to maintain a sanitary prophylactic supervision. No single installation or laboratory, where radioactive materials are used, should begin operation without expert advice from a competent commission on the maintenance of safety measures.

One of the most important hygienic problems in the field of radiology demanding prompt solution is the working out of a more rational hygienic standard and the setting up of limits of permissible concentrations of

radioactive substances which will completely exclude the possibility of chronic exposure to small radiation doses.

A basic demand of hygienists in contemporary atom technology is the creation of a completely closed system for liquid radioactive products so that they would not have to be discarded into open tanks even in minimal quantities. No less important are the questions of prophylaxis in conjunction with the pollution of the atmosphere by very small quantities of radioactive products. Atomic energy installations should not bring about a marked increase in the natural radioactive content of the background in adjoining areas.

Experience shows that, with the carrying out of necessary prophylactic measure, the observance of personal hygiene and proper cultural level of labor, work with radioactive substances and radiations can be as harmless as any other.

It is necessary to improve scientific research a great deal on questions of labor hygiene in work using ionizing radiations. For further work on questions of theoretical and practical therapy and prophylaxis of radiation dosages, it is very important that doctors with various specializations should have basic information on medical radiology. At the present time no hygienic institute or chair can exist which does not include, in one way or another, work on the prophylactic problems of radiology.

In the discussions following the reports of A. I. Burnazyan and A. A. Letavet more than 30 persons took part. Among them F. G. Krotkov, A.V. Kozlova, M. N. Pobedinsky and others. Noting the important work which was done on the expansion of nomenclature and the improvement of the quality of produced isotopes, they brought up a series of suggestions on the organization of scientific research work, on the training of cadres in the field of medical radiology, on the improvement of the supply of radiometric and analytical equipment and radioactive isotopes. A great deal of attention was given during the discussions to the hygienic problems in the field of medical radiology and various questions of protective techniques. Many of those who took part in the discussion underlined the necessity of studying genetic consequences of ionization radiation.

The conference marked an important stage in the development of Soviet medical radiology and the Ministry of Public Health has already taken steps towards the implementation of the proposals made at the meeting of the medical radiology section.

Ya. G.

INTERNATIONAL CHRONICLE

CONSTITUTION

OF

THE JOINT INSTITUTE FOR NUCLEAR STUDIES

SECTION I

CREATION AND LOCATION OF THE INSTITUTE

Article 1

The Joint Institute for Nuclear Studies, hereinafter referred to as "Institute," shall be an international scientific-research organization, created by the Agreement for the organization of such an institute concluded among the following governments on the 26th of March, 1956:

The People's Republic of Albania, the People's Republic of Bulgaria, the Hungarian People's Republic, the German Democratic Republic, the Chinese People's Republic, the Korean Popular-Democratic Republic, the Mongolian People's Republic, the Polish People's Republic, the Romanian People's Republic, the Union of Soviet Socialist Republics, and the Czechoslovakian Republic.

Article 2

The Institute shall be located in the Union of Soviet Socialist Republics, in the town of Dubna, Moscow district.

Postal address: P. O. Box No. 79, Central Post Office, Moscow.

Article 3

The Institute shall be a legal entity and, according to the laws of the country wherein it is situated, shall possess the capacity and status necessary for the realization of its aims and functions.

The Institute shall have the right of free access to foreign publications.

The Institute shall have its own seal, an impression of which is affixed to this Constitution.

SECTION II

AIMS AND FUNCTIONS OF THE JOINT INSTITUTE FOR NUCLEAR STUDIES

Article 4

The purpose of the Joint Institute for Nuclear Studies is:

to guarantee the coordination of theoretical and experimental research done by scientists of Institute-Member States in nuclear physics;

to further the development of nuclear physics in Institute-Member States by the interchange of experience and of theoretical and experimental research results;

to maintain communication between the national and international scientific-research organizations and other organizations interested in the development of nuclear physics and in the exploration of new possibilities for the peaceful use of atomic energy;

to help develop specialized skills of every description in the scientific-research personnel of Institute-Member States.

The Institute will be concerned solely with the development of peaceful uses for nuclear energy to benefit all mankind.

Results of scientific research done at the Insitute shall be announced either by publication or at scientific conferences and meetings.

Reports on the work accomplished shall be sent to all Institute-Member States.

SECTION III

MEMBERSHIP IN THE JOINT INSTITUTE FOR NUCLEAR STUDIES

Article 5

The members of the Joint Institute for Nuclear Studies are those States which signed the Agreement concerning the organization of this Institute.

Other States, wishing to participate in the work of the Institute and concurring with the conditions of the Agreement concerning the organization of the Institute, shall become Institute Members upon the decision of a majority of the Institute-Member States.

The amount of participation in Institute maintenance and construction expenses allotted newly joined Institute-Member States shall be decided by the Finance Committee and approved by the Governments of the Institute-Member States.

Article 6

All Institute Members shall participate equally in the scientific work and management of the Institute.

Article 7

The Institute Board of Directors, with regard to the principle of cooperation, shall decide individually all questions regarding the use of the Institute for work by non-Member State scientists.

The Institute Board shall determine the size and form of compensation required for the use of Institute equipment and materials according to the agreement reached with the interested State, scientist, or scientific institution.

Article 8

Any Institute-Member State can resign from membership.

Written notice of resignation from the Institute shall be submitted by the Government of the State wishing to withdraw from the Institute to the Institute Board no later than three months before the termination of the then current fiscal year.

Resignation from the Institute shall become official upon termination of that fiscal year in which the State declared its withdrawal from the Institute. After reviewing the budget for the fiscal year in which the State announced its withdrawal from the Institute, the Finance Committee shall determine the amont of monetary reimbursement due the resigning State according to the share of capital outlay for the Institute apportioned that State.

SECTION IV

FINANCE COMMITTEE AND BUDGET

Article 9

A Finance Committee consisting of representatives from all Institute-Member States shall be set up to control the financial affairs of the Institute and approve the budget.

Each Institute-Member State shall have one representative on the Finance Committee. Members of the Committee whall be appointed by the Governments of the respective States.

The Finance Committee shall convene at least once a year. Representatives of each State in turn shall preside over the sessions.

Resolutions of the Finance Committee shall require a two-thirds majority vote for adoption.

Article 10

The Finance Committee shall examine and approve:

a) the estimated costs of financing Institute scientific and economic works;

b) the departmental structure, personnel, and official pay rates for all categories of Institute workers;

c) amounts and terms of monetary payments toward Institute construction and maintenance from Institute-Member States according to the proportionary scale provided in the Agreement of the Institute-Member States;

d) the plan for financing capital construction.

The Finance Committee shall generally control all financial affairs of the Institute.

Article 11

A budget for the Institute covering the period from January 1st to December 31st inclusive shall be drawn up each year.

Article 12

In the budget presented by the Board to the Finance Committee, provision shall be made for all Institute expenses, itemized as follows:

a) financing of scientific researches and payment of Institute workers;

b) cost of developing scientific research and other Institute objectives;

c) money to reward and encourage Institute workers, for length of service, etc., and to give financial help to workers when and if needed;

d) other expenses incurred in the course of the Institute's activities.

Article 13

Each Institute-Member State shall produce on the dates specified monetary payments, according to the budget approved by the Finance Committee, toward the maintenance and development of the Institute and its objectives.

These payments shall be payable in the currency of the country wherein the Institute is situated.

In those cases where the Joint Institute for Nuclear Research requires currency to purchase equipment, instruments, materials, technical scientific literature or periodicals from States not belonging to the Institute, Institute-Member States shall pay a portion of the sum allotted them by the Agreement in the currency of those States. The amount of the sum in this currency will be established by the Finance Committee.

The value of equipment, materials, and instruments supplied by Institute-Member States, as well as the value of individual work accomplished according to Institute laws may be computed as part of the allotted participation.

The manner of computation shall be established by the Finance Committee.

Article 14

The scale of allotted participation in the Institute development and maintenance costs shall be revised both upon the admittance of new Institute-Member States and upon the resignation of any State from membership, and a new scal shall be presented to the Governments of the Institute-Member States for approval.

Article 15

During the fiscal year, the Institute may partially redistribute the moneys itemized in the budget under the divisions of capital construction and exploratory work.

Article 16

At the end of each fiscal year, the Institute Board shall report to the Finance Committee on the budget balance according to its status at that time.

The Finance Committee shall specify the date on which the report is to be presented.

SECTION V

SCIENTIFIC COUNCIL OF THE JOINT INSTITUTE FOR NUCLEAR STUDIES

Article 17

The Scientific Council of the Institute shall consist of three scientists from each Institute-Member State to be appointed by their States.

The staff of the Scientific Council shall include the Director and Vice-Directors of the Institute (who are chosen according to Article 20 of this Constitution), who shall have the right to vote.

Laboratory Directors, who have not been appointed Members of the Scientific Council by their various Governments, shall be included in the staff of the Scientific Council with the right of participating in the debates.

Article 18

The Scientific Council of the Institute shall:

a) consider and approve the Institute scientific research programs;

b) examine the results of completed scientific research programs and also the results of individual studies;

c) consider other questions concerning the scientific work of the Institute.

The Scientific Council shall convene at least twice a year.

Article 19

The Institute Director shall be president of the Scientific Council.

The Scientific Council shall announce its own rules of procedure.

SECTION VI

BOARD OF DIRECTORS OF THE JOINT INSTITUTE FOR NUCLEAR STUDIES

Article 20

The Institute shall be headed by a Board of Directors consisting of an Institute Director and two Vice-Directors, to be elected from the scientists of the Institute-Member States by a majority of these States. The Director shall be elected for a three-year term, the Vice-Directors for a two-year term.

The Board of Directors shall be elected by the plenipotentiary representatives of the Institute-Member States.

Article 21

The Institute Director shall be a plenipotentiary officer, who shall maintain relations with the appropriate institutions of the Institute-Member States in all questions concerning the work of the Institute.

The Institute may establish direct communication with scientists and scientific organizations of other countries.

The Institute Vice-Directors shall assist the Director in the management of the Institute, substitute for him in his absence, and shall have a responsibility equal to his for all activity of the Institute.

Article 22

The Institute Board is responsible to the Governments of the Institute-Member States for the activity of the Institute and shall report to them periodically.

Only decisions of the Finance Committee and the Scientific Council may direct the Institute Board in the management of the Institute; the Institute Board shall not obey any orders from individual Institute-Member States.

Article 23

On the appointed dates, the Institute Board shall present a yearly budget estimate and a report of the budget balance to the Finance Committee.

Article 24

The Institute Board shall direct the scientific work of the Institute according to the program for scientific research procedure approved by the Institute Scientific Council, and shall direct the financial affairs according to the decisions of the Finance Committee.

The Institute Board shall have the right of partially altering the scientific research programs assigned to the various Institute Laboratories.

The Board must inform the Institute Scientific Council of all such changes or modifications.

Article 25

Each year, the Institute Board shall present to the Institute Scientific Council for review and approval drafts of summary programs for scientific research works, drafts of programs for the future development of the Institute, and a report of the Institute's scientific work.

Article 26

The Institute Director shall be manager in chief of Institute assets. He shall be in charge of all the Institute means and property.

Article 27

The Institute Director shall have the right:

a) to hire and discharge employees according to the Institute Regulation regarding personnel;

b) to establish or alter within the official wage limits approved by the Finance Committee the wages of all employees, and to initiate individual pay raises for highly skilled workers of up to 50% of the original wage within the limits of the sums estimated for this.

SECTION VII

LABORATORIES OF THE JOINT INSTITUTE FOR NUCLEAR STUDIES

Article 28

The Institute staff shall include: a Nuclear Problems Laboratory, a High Energy Laboratory, a Neutron Physics Laboratory, and a Theoretical Physics Laboratory, each of which shall coordinate the research in their respective fields of nuclear physics.

The Institute Laboratories shall consist of scientific departments and sections.

Decision of the Institute Scientific Council can change the number of Laboratories to fit the requirements of the work at hand, and decision of the Institute Board of departments and sections.

Article 29

Scientists from Institute-Member States will be chosen by the Institute Board to serve as Laboratory Directors and subsequently approved by the Scientific Council; their function shall be the management of the Laboratories.

The Laboratory Directors shall be responsible to the Institute Board for their actions and for the work of their Laboratories.

Article 30

The Laboratory Directors shall direct all scientific research work in their Laboratories according to the program approved by the Institute Scientific Council.

Laboratory Directors, with the approval of the Institute Board, shall have the right of partially altering the outlined course of scientific research work.

Through the Institute Board, Laboratory Directors may select personnel, hire and discharge Laboratory employees, determine and alter, within the approved pay-rate limits, wages paid Laboratory employees according to the extent and quality of each employee's work and may declare bonuses or fines.

Article 31

A Scientific Council shall be set up in each Laboratory, the staff of which shall be approved by the Institute Scientific Council.

The Laboratory Director shall be the president of the Laboratory Scientific Council:

The Laboratory Scientific Council:

a) shall prepare programs for the scientific research work assigned the Laboratory;

b) shall examine results obtained by such scientific research work and by individual studies;

c) shall confer doctorates and Bachelor degrees in the mathematico-physical and technical sciences;

d) shall consider other questions concerning the scientific work of the Laboratory.

Article 32

On specified dates, Laboratory Directors shall present a draft program of the Laboratory's scientific research work, a report on the Laboratory's work, and requests for needed materials and equipment to the Institute Board.

SECTION VIII

ADMINISTRATIVE-ECONOMIC MANAGEMENT OF THE JOINT INSTITUTE FOR NUCLEAR STUDIES

Article 33

The Institute Director shall appoint one of his assistants as Administrative Director to manage the administrative-economic work and construction of the Institute.

Article 34

The Administrative Director shall direct the work of the departments within his jurisdiction, which departments provide the framework of the Institute. He shall have the right of hiring and discharging workers in these departments.

Article 35

The Administrative Director as proxy for the Institute Director shall manage the assets and shall be respon-

sible for the correct expenditure of Institute funds as outlined in the budget approved by the Finance Committee.

The Administrative Director shall be subordinate to and responsible for his actions to the Institute Director.

SECTION IX

CONCERNING THE PERSONNEL AT THE JOINT INSTITUTE FOR NUCLEAR STUDIES

Article 36

All persons on the Institute staff shall be employees of the said international scientific organization and under obligation to further its aims and undertakings.

Article 37

Institute employees shall be recruited from Institute-Member States citizens.

The Institute Board shall consider the proposed contingents from each Institute-Member State, and the Scientific Council shall approve them.

The question of scientific workers sent by Institute-Member States for short-term work at the Institute shall be decided by the Institute Board.

Article 38

The obligations and rights of Institute personnel shall be determined by a Code of Regulations for personnel of the Joint Institute for Nuclear Studies. Personnel of the Institute shall be subject to the laws of the country in which the Institute is located.

Article 39

The Institute Board may take university students or graduates who are citizens of Institute-Member States for practical study in the Institute Laboratories. In such cases, the States shall stand the expenses incurred from the practice of their students or novices. The form and term of this practical study shall be determined by the the Institute Board.

SECTION X

LIQUIDATION OF THE JOINT INSTITUTE FOR NUCLEAR STUDIES

Article 40

The Institute for Combined Nuclear Research can be liquidated by agreement of the Institute-Member State Governments.

Upon liquidation, all Institute equipment and all principal, subsidiary, and adminsitrative buildings shall become the property of the Union of Soviet Socialist Republics, wherein the Institute is situated. Other Institute-Member States shall receive monetary reimbursement proportionate to the amount of participation assigned each of these States in capital outlay for the Institute.

Upon liquidation all Institute monetary assets on hand, except those portions required to pay Institute obligations, shall be distributed among those States being Institute Members at the time of its liquidation, in proportion to the amounts of monetary payments actually contributed by these States during their participation in the work of the Institute.

SECTION XI

RATIFICATION OF THE CONSTITUTION

Article 41

This Constitution shall be ratified by the Council of Plenipotentiary Representatives of the Institute-Member States.

The ratified copy of the Constitution shall be kept in the Institute.

SECTION XII

AMENDMENTS TO THE CONSTITUTION

Article 42

This Constitution may be amended or changed.

Proposals to change the Constitution shall be directed to the Institute Board. The Board shall also have the right to propose changes in the Constitution. Upon the acceptance of such proposals by a majority of Institute-Member States, the Institute Board shall consider those changes as part of the Constitution.

This Constitution for the Institute has been drawn up in the Russian language on the 23rd of September, in the year 1956. Witnessed copies of this document shall be sent by the Institute Board to all Institute-Member States.

In witness of which the Plenipotentiary Representatives of the Institute-Member State Governments have signed this document and certified it with the Institute seal.

Authorized by the Government of the People's Republic of Albanian	Prifmi, Mikhal
Authorized by the Government of the People's Republic of Bulgaria	Gerasimov, Lyuben
Authorized by the Government of the Hungarian People's Republic	Kishsh, Arpad
Authorized by the Government of the Democratic Republic of Viet Nam	Chan Dai, Ngia
Authorized by the Government of the German Democratic Republic	Rambush, Carl
Authorized by the Government of the Chinese People's Republic	Van Gan-, Chan
Authorized by the Government of the Korean Popular-Democratic Republic	Kim Khen, Bon
Authorized by the Government of the Mongolian People's Republic	Sodnom, Namsrain
Authorized by the Government of the Polish People's Republic	Billig, Wilhelm
Authorized by the Government of the Romanian People's Republic	Khulubei, Khoriya
Authorized by the Government of the Union of Soviet Socialist Republics	Slavsky, Efim Pavlovich
Authorized by the Government of the Czechoslovakian Republic	Kozheshnik, Yaroslav

WITHIN THE SOVIET UNION

AT THE ATOM PAVILION OF THE ALL-UNION INDUSTRIAL EXPOSITION

(Atomic Raw Material Department)

At the "Atomic Energy" pavilion of the All-Union Industrial Exposition considerable place was given to mineral raw materials. Show cases and stands with various exhibits and other material given over to the properties and study of mineral raw materials were located in Hall No. 2.

The central spot here was taken over by two showcases in which were exhibited samples of mineral and uranium ores found in the USSR.

The minerals were arranged in systematic order according to class:

I. Uranium oxides, uranium-thorium oxides.
II. Hydrated uranium oxides (uranates).
III. Uranium silicates.
IV. Uranium phosphates.
V. Uranium arsenates.
VI. Uranium vanadates.
VII. Uranium carbonates.
VIII. Uranium sulfate-carbonates.
IX. Uranium sulfates.
X. Uranium molybdates.
XI. Organic uranium minerals.
XII. Titanates with uranium.
XIII. Titano-tantalo-niobates.
XIV. Tantalo-niobates containing uranium.

Together with the minerals, well known as primary uranium ones, pitchblende (Fig. 1),* uraninite, and the secondary minerals, autunite (Fig. 2) tyuyamunite and others, many uranium minerals first discovered and studied in the USSR are brought to one's attentions. Among these are lermontovite – hydrated uranium phosphate (Fig. 3) forming grey-green clusters and kidney-like aggregates, tar-black khlopinite, microcrystalline aggregates of nenadkhevite, uranium chern (Fig. 4) and others.

Among these minerals, some are of practical interest as basic uranium bearers, others are used as prospecting indications.

In particular, from the group of phosphates with an admixture of uranium, phosphorite takes on considerable importance, forming in some cases large scale deposits, from the ores of which one can obtain uranium as a concomitant component. Also of interest is the new uranium mineral, nenadkevite, forming industrial ores.

As good prospecting indicators, one can use various secondary uranium minerals, most often yellow or yellow-green in color, (Figs. 5 and 6) especially micaeous uranium (uranium phosphates, arsenated and vanadites, sulfocarbonates, etc.).

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* See note on p. 56 of this journal regarding the referenced figures.

Among the uranium ores, the greatest space was given to pitchblende ores, represented by various paragenetic groups:

– in quartz schist albitized sandstone, quartz porphyry tufas, hematite and hematite magnetite ore;

– with carbonates in chloritized schist, amphibolite, pyrite, chalcopyrite, molybdenite, arsenidite and diarsenidite, in various strata.

A great number of the samples are from ores of sedimentary origin, uranium bearing sandstones, calcium deposits, schists, coals, and phosphorites.

Ore samples from the oxidized zone of uranium deposits are distinguished by brilliant shades of yellow, green, reddish brown.

The mineral and uranium ore samples displayed in the cases show their diversity, and hence the diversity of raw material sources for the obtaining of uranium.

Some samples of uranium ores are separately displayed. They are interesting because of their high metallic concentration – almost solid concretions of pitchblende and considerable size of these excretions.

Special displays acquaint the visitors with the methods used in the USSR for prospecting for uranium ores and the equipment used. Photographs and models show uranium prospecting from an airplane, a helicopter, a car, and also on foot; gamma logging of drill holes, etc.

Here too are displayed several series of apparatus used in various stages of prospecting and other research with scintillation counters and gas-filled counters with a recounting arrangement.

In the USSR the methods for investigating radioactive mineral raw materials are well developed including that of luminescent uranium analysis. Various original luminescent instruments were displayed at the exposition – luminoscopes and luminescent photometers used under field conditions and in laboratories.

Geologists were very much interested in a global map hanging on the wall at the far end of the hall; this map is a first attempt to show data on the age of various regions of the earth's crust and is based on numerous determinations of absolute age of the strata by Soviet geochemists and foreign investigators. It is interesting to note that up until now the age of the earth's crust was thought to be approximately 3 billion years; the map displayed determined it to be 5.5 billion years old.

M. K.

AT THE ATOMIC POWER STATION OF THE HIGH AUTHORITY FOR ATOMIC ENERGY FOR THE USSR COUNCIL OF MINISTERS

Numerous soviet and foreign delegates are becoming acquanited with the organization and the principles of operation of the world's first atomic power station.

More than 10,000 representatives of various scientific and public organizations of our country have visited the atomic power station. Delegations from the USSR Academy of Science, headed by its president, Academician A. N. Nesmeyanov, workers from the USSR Academy of Science Institute for Physical Problems, from the Institute of Automation and Remote Control from the USSR Academy of Science Energy Institute and from many other institutions, concerns, and public organizations, visited the station.

According to data as of the 1st of September 1956, it had been visited by more than 2,000 representatives of 52 world governments. Among them were Chinese, Koreans, French, British, Indians, Indonesians, Americans, Germans, Egyptians, Syrians, Mexicans, Uruguyans. Among the honored visitors at the station were outstanding government officials such as O. Grotewohl, Kim Ir Sen, Nehru, Soekarno, Tito, V. Ulbricht, U. Nu, Ho Shi Min, Chzhu De.

Approximately 1,000 foreign students and specialists became acquainted with the work of the atomic station, among them such noted scientists as Cockreft (Britain), Babha (India), more than 500 political workers, around 500 representatives of business circles and about 200 foreign correspondents.

These figures speak not only of the tremendous interest shown abroad in the achievements of Soviet science and technology, but also of our constantly growing cultural and scientific ties.

B. A. Semenov

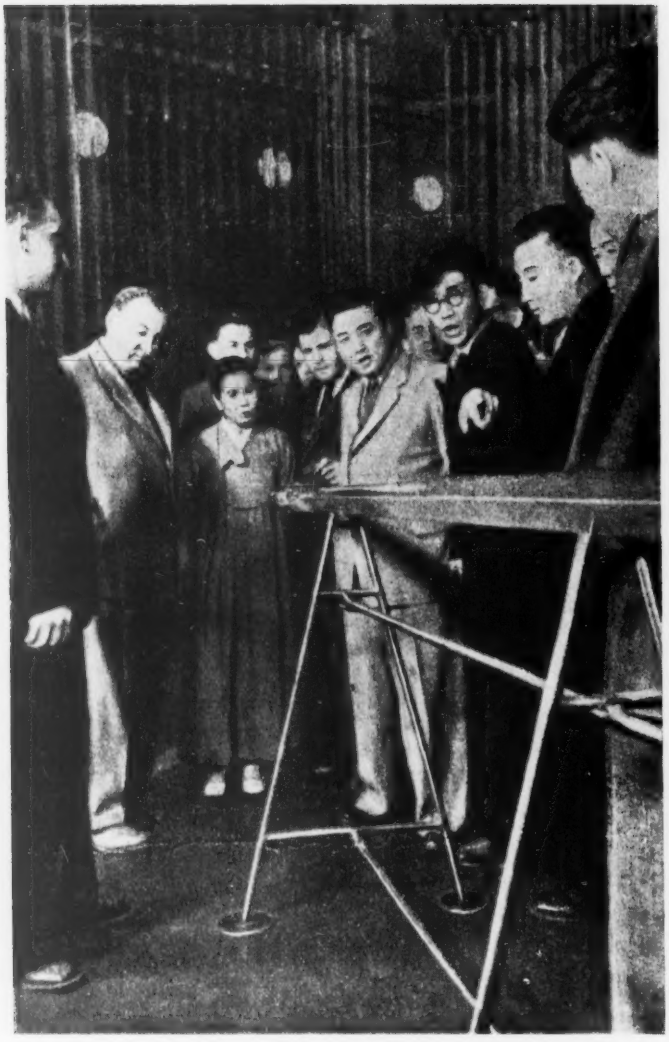

Fig. 1. Comrade Kim Ir Sen at a section of the technologoical canal of the atomic power station of the High Authority for Atomic Energy for the USSR Council of Ministers.

President Sukarno signing the book of honored visitors at the atomic power station.

Fig. 3. Mr. Radkhakrishnan (India) leaving the atomic power station building.

AID ACCORDED TO ATOMIC SCIENTISTS COMING FROM THE PEOPLE'S DEMOCRACIES

Letter from Corresponding Member of the Academy of Sciences of the
Romanian People's Republic

I have learned with lively interest and great satisfaction of the far reaching plans of the High Authority for Utilization of Atomic Energy for the USSR Council of Ministers, according to which the energy economy of the USSR will have before the completion of the present five-year plan; atomic power stations having a total power of 2.5 million kw; the first atomic powered ice breaker will be launched and put into operation; the manufacture of artificial radioactive isotopes is being greatly increased, which will make possible their utilization in metallurgy, mechanical engineering, chemistry, geology, extractive industry, agrotechnology, medicine, etc.

In the carrying out of the scientific part of this program, a part will be played by the Joint Institute for Nuclear Studies and Romanian physicists are proud that they will be able to work at this Institute. Representatives of the Romanian People's Republic will try to borrow from and use widely the great experience accumulated by the specialists of the USSR and other countries. For us, Romanians, it is clear that, being limited in material and human resources, without the help of the Soviet Union we would be able only with the greatest of difficulties and extremely slowly to liquidate our lag in the field of atomic science and its practical application, which was brought about as a result of unfavorable historical conditions in which the Romanian people lived before liberation from the yoke of its own and foreign bourgoisie.

The help of the Soviet Union, contributing to the progress of atomic physics and its application in the Romanian People's Republic, is by no means limited to the above stated aid. In January 1955 the government of the USSR offered to a number of friendly nations, among them to our country also, its scientific and technical assistance for the construction of a material base for the development of nuclear research in each of these countries. An agreement was concluded between the governments of the Romanian People's Republic and the Soviet Union by which the USSR took upon itself the responsibility of providing Romania at exclusively favorable terms an experimental reactor of 2000 thermal kw and a proton accelerator for energy of 25 Mev.

Work in connection with the carrying out of the agreement is in full swing. Already, on the land of the Atomic Physics Institute of the Romanian People's Republic Academy of Sciences, walls are going up for the special buildings which will house the reactor and the accelerator together with the necessary laboratories. From the USSR there is a constant flow of machinery, apparatus, and special materials for these two installations. Working on the assembling of the installation are Soviet, as well as Romanian specialists, who had received practical training in the Soviet Union. It can be expected that the reactor and the accelerator will be in operation in 1957. They will guarantee the production of artificial radioactive isotopes in quantities sufficient for the scientific and technical needs of the country during the next few years.

Scientific co-workers at the institute have already begun preparations for work utilizing radioactive isotopes. The general themes of the Institute include questions on the physics and optics of neutrons, nuclear spectroscopy, cosmic radiations, chemistry and physics of radioisotopes, radiochemistry, metrology of radiation and so forth.

In order to prepare cadres for the operation of basic installations special yearly courses for chemists, biologists, doctors, and engineers are being organized at the physico-mathematical faculty of the K. I. Parkhon Bucharest University to acquaint them with the technique of the work with artificial radioactive isotopes. The

cadres of scientific workers at the Institute are supplemented by the best graduates of the physico-mathematical faculties.

As long as we do not yet have our own radioactive isotope production the Atomic Physics Institute and other scientific institutions are getting them from the USSR. Oil and coal industries are using Soviet equipment for gamma-logging. Romanian researchers in various specialized fields have been trained in the USSR in the techniques of isotope usage. Soviet scientific literature has played a principal role in forming and completing the training of our students in the field of atomic energy.

According to an established marvelous tradition, on the monthly feast days of Romanian-Soviet friendship, we retotal the achievements of our friendship. It is a great joy for us that with the passing of time the friendly ties between our countries are multiplying, as a direct result of the consistent and principal policies of international solidarity carried out by the Soviet government. Aid given us in the multisided development of nuclear research and its practical applications are an inalienable part of this policy. May it be allowed to the author of these lines – a physicist working in the field of nuclear physics – to express his special gratitude for this private side of Soviet help, which permits him and his colleagues to take part in the application of atomic energy to peaceful uses for the good of all, for the uninterrupted raising of the living and cultural standards of the people, to a patriotic intellengentsia dedicates all its energies – as it learned to do from its Soviet colleagues.

Corresponding Member of the Rumanian People's Republic Academy of Sciences, member of the Scientific Council of the Atomic Physics Institute, professor, doctor

Al. Sanielevich

APPLICATION OF RADIOACTIVE ISOTOPES IN INDUSTRY, SCIENCE, AND AGRICULTURE

(From Published Material)

Heavy Metallurgy

In the Stalin metallurgical plant, with the aid of radioactive cobalt held in small containers, irradiations of the welded seams of a blast furnace jacket were carried out directly during the process of assembly; that is under conditions completely impossible for x-rays. Using such containers, defectoscopists can find inner defects in the walls of steam boilers, gas pipes, etc.

The duration of smelting in open hearth furnaces and the purification of steel from sulfur and phosphorus during the early stages of the smelting depend a great deal on the order of loading and on the quantities of solid materials. With the help of isotopes a number of plants "tag" raw materials – lime or ore – and by measurements of the radioactivity of metal samples or slag determine the speed with which active slag is formed. In this way the dependence of the speed of melting of the limestone and ore on technological factors is demonstrated. In the same way is determined the speed of scrap melting. For this purpose the metallic part of the furnish is tagged. Research of this type is now growing at the plants of "Azovstal," Stalin and Makeevka, and in the Magnitogorsk and Kuznetsk combines.

After the emergence of the steel in the open hearth, it is not always possible to evaluate the condition of the furnace weld by means of an ordinary examination, nevertheless a nondiscovered defect can bring about a serious accident in succeeding smeltings. Radioisotopes forestall this possiblity. At the "Azovstal" plant radiophosphorus in magnesite ampoules was buried in various parts of the furnace. The appearance of radioactivity in slag samples which were taken out as the smelting progressed pointed to a disintegration of the welding.

In the realm of analytical chemistry, applicable to metallurgical problems, research was directed along two lines with the help of radioactive isotopes. The first was the checking into, and perfecting of, ordinary methods of chemical analysis, for example, on phosphorus. In this case with the melting of steel scrap or ore, a small quantity of radiophosphorus was added. As the analysis progressed along its various stages, the intensity of radioactive radiation of the molten samples could be determined. In the absence of losses, the sum of the radioactivities of the molten masses, taken during all stages of the analysis, should be equal to the radioactivity of the original charge.

The second line followed was the development of methods for quick analysis of steel and slag, for any one element most important in the given technology by the introduction of radioactive isotopes immediately into the steel smelting furnaces. Thus for the technology of reworking cast iron with a high phosphorus content a method has been worked out at the "Azovstal" plant for the quick determination of phosphorus pentoxide in slags. It has been established that with the expenditure of 0.04-0.05 m curies of radioactive phosphorus isotope per ton of metal, a sufficient accuracy of analysis is reached in a much shorter time in comparison with chemical analysis. This method permits the control of the slag melting schedule and the more precise sorting out of the slag as fertilizer. A similar method has also been worked out for the determination of phosphorus metal while the reworked cast-iron is being smelted in the converter. It can be used successfully in the new technology of metallurgical reworking and in research where the speed of determination of the phosphorus content in metal or slag influences the operation of the process. (Industrial-Economic Gazette, Sept. 9, 1956).

In the struggle for technical progress, Ukrainian metallurgists constantly make greater use of tagged atoms of radioactive elements. With the help of radioactive cobalt and without shutting down the blast furnace it is possible to determine the condition of its walls lined with fireproof brick.

Using radioisotopes the workers determine the speed of steel ingot crystallization; they determine the content of phosphorus in open hearth slag much more quickly than before, observe the process of slag formation, and fix the moment of finishing the process of melting iron ore and limestone during smelting.

Using tagged atoms, metallurgists determine the content of silica in the ore considerably faster than they could by chemical means. Radioactive isotopes are widely used for the determination of the magnitude and character of iron ore strata beds and for the operation of a series of industrial processes at the crushing-sorting and enriching factories . (Ukrainian Pravda, Aug. 4 1956).

At the "Dneprospetsstal" in Zaporozhe a physical research laboratory is under construction equipped with the very latest apparatus. In this laboratory research using radioactive isotopes is carried out on the process of electrosteel melting. In particular with the help of radioactive calcium, the cause of ball-bearing steel pollution by furnace slag is being studied. (Pravda, Sept. 21, 1956).

Machine Construction

Research carried out at the Science-Research Institute, NATI, shows that it is possible to determine the influence of oiling, of prime-mover power, of the number of revolutions of the calendar, of air dust pollution, and of work stoppage (experimental) on the rate of prime-mover wear, as well as metal tolerance where one surface rubs against the other, all solely by means of radioactive isotope use.

With the help of radioactive isotopes it is possible to measure the wearing out of parts within one tenth of a millionth of a gram.

Experiments conducted at the Machine Construction Institute of the Academy of Sciences of the USSR and in other organizations gave interesting results. It was shown that with the aid of radioactive isotopes one could thoroughly study the wearing out of an instrument without stopping the cutting process. In particular one can determine the relationship of the wearing out time to the speed of feeding, depth of cutting, oiling and cooling liquids and material being worked.

One can also determine how the scrap produced by the cutting tool is distributed under various cutting conditions; how much of it becomes shavings, how much of it goes into the end product and into the oiling-cooling liquid, how much is separated as dust. All this is very important in setting up cutting schedules. (Industrial-Economic Gazette, Oct. 26, 1956).

A radioactive isotope laboratory has existed for five years at the Transportation Machinery Construction Factory. Among the questions solved by the laboratory one must mention the following: determination of calcium in slag during smelting in an acid electroarc furnace and the wearing out of some bearing alloys used in a TE-3 engine. Research is being carried out on the influence of lubricant types and surface cleanliness on the wearing out of thermal installation pinions, on the distribution of alloyed elements in steel as a function of the cooling rate, etc. (Red Banner, Kharkov, Oct. 7, 1956).

Oil Industry

In the Archedinsk Oil Industry Organization radio-logging has been widely used. It has become a compulsory means of drill-hole surveying. With the use of radioactive isotopes it is possible to determine when the worked shafts are no longer hermetically sealed. Thus with the help of the cobalt isotope it was possible to determine the depth at which the hermetic sealing of shafts No. 39 and 27 was broken.

By means of the same isotopes work was considerably speeded up on the exploration of the Devonian shaft No. 93. A new oil bearing strata was found in it. (Stalinskaya Pravda, Aug. 19, 1956).

Metal Welding

Application of radioactive isotopes to welding at the present time follows three directions: in the defectoscopy of welded seams, in the use of isotopes in plans for automatic regulation and control of technological pro-

cesses, and finally in the study with the aid of radioactive isotopes of a series of metallurgical properties of metal welding.

For the defectoscopy of welded seams the radioactive isotope cobalt-60 with a rather penetrating gamma radiation has been widely used; also isotopes of europium-154, iridium-192, cesium-137 and thulium-170 with less penetrating radiation.

At the E. Paton Electro-Welding Institute of the Academy of Sciences of the Ukrainian SSR, there has been developed a method of automatic regulation of the metal bath level with electroslag welding with application of the radioactive isotope cobalt-60. Difference in the coefficient of absorption of gamma radiation between slag and metal allowed the construction of an automatic regulator of the bath level, i. e., made automatic the process of welding metals of several thicknesses. (Industrial Economic Gazette, Oct. 10, 1956).

Equipment Technology

A special apparatus – wall differential meter – has been created by TSNIL the collective of the Co-Workers of the Central Scientific Research Laboratory, GOSGORTECHNADZOR of the USSR.

The sample of the wall differential meter, P-3 which was exhibited at the All-Union Industrial Exposition is portable, light in weight, easily manageable. Whereas the industrial methods now used for wall differential testing of pipes are complicated, cumbersome and imprecise.

Wide perspectives are open to the meter in various branches of industry; in heavy metallurgy for the quick accurate measurement of the walls of newly cast pipes, in the repair of steam boilers, water pipes, drainage.

The meter was shown at the Geneva Conference on the Peaceful Uses of Atomic Energy and was highly praised. This apparatus is now being tested under manufacturing conditions at one of Leningrad's ship building concerns. Yesterday a telegram came to the laboratory from Leningrad saying "Tests of the meter carried out on steel and copper pipes. Results good."

The meter is not the only atomic apparatus invented by engineer Yu. G. Kardash; his gamma-slurryometer could be seen at all the earthworks during the building of the Kuibyshev, Stalingrad, Kakhov and other hydroelectric stations. It determines the percent content of earth in slurry; slurry–mixture of soil and water. Without it the machine operator at the earthworks would be working blind. Now the co-workersof TSNIL of GOSGORTECHNADZOR are working on the question of using atomic energy to guarantee safe working conditions for miners. (Komsomol Pravda Oct. 10, 1956).

The Scientific-Research Institute for Thermal Energy Equipment, NII TEPLOPRIBOR, is carrying out scientific research and experimental construction work on the creation of various automatic equipment based on the application of radioactive isotopes.

Lately a series of new equipment has been created some of which has successfully passed the test and is now being put in production.

A radioactive density meter for liquids, PZhR-1, is designed for the automatic measuring of the density of any liquid in the density range of 0.1 up to 2 grams/cc. (Industrial-Economic Gazette, Oct. 14, 1956).

Food Industry

The All-Union Scientific-Research Institute for the Canning Industry has finished installation plans for the irradiation of food products.

The installation is designed for the sterilization of food products by an irradiational dose of $3 \cdot 10^6$ r for 20-30 min. and also disinfecting, pasteurization, at doses of from 10^4 to 10^6 roentgens.

Chemistry

Questions of the immediate use of the nuclear energy processes in chemistry have been actively worked on by the Collective of the Moscow L. Ya. Karpov Scientific-Research Physical Chemical Institute.

At the present time at chemical plants with the help of potassium permanganate, oxidized paraffins are produced, from which fatty acid is obtained which is a basic raw material for the manufacture of various washing media.

Research carried out at the Institute showed that paraffins can be oxidized without catalyzers with the help of radioactive radiations; the resulting fatty acid has better qualities. Energy of nuclear processes produces, in this case, more complete oxidation.

One of the initial products for the manufacture of plastics is phenol, which is obtained by the oxidation of benzol with the help of a catalyzer. Usually in order to prepare one kg of phenol, two kg of benzol must be oxidized. Laboratory research at the Institute showed the possibility of obtaining, with the help of radioactive radiations, one kg of phenol from one kg of benzol. Thus with the same expenditure of energy, Soviet scientists have been able to produce three times the amount of a substance than that produced by foreign scientists.

Hexachlorobenzene is widely used in agriculture. To produce it, benzol is chlorinated. As a result of this process four isomers are produced of which only one, the gamma isomer, has the necessary properties. Usually the gamma-isomer makes up 12-15% of the whole. The use of radioactive radiations made it possible to increase the gamma-isomer content up to 25%.

It has been established that atomic energy also influences the speed of a polymerization process.

Work is contemplated on the synthesis of a series of new products. Scientists have established that benzol, when irradiated in a mixture with ammonia gives off aniline directly and immediately. Institute workers have a great interest in the development of radiochemistry. Among them Professors V. Veselovsky and M. Proskurin; candidates V. Karpov and A. Zimin; senior scientific co-workers A. Balelk, V. Orekhov and others. (Industrial Economic Gazette, Nov.4, 1956).

Agrotechnique

Collaborators at the Laboratory of Microbiology and Physiology at the Scientific Research Institute of Agriculture of South East USSR, candidates in science A. E. Fomin and N. K. Astakhova established that extra feeding of wheat and corn with organic phosphorus, speeds up the ripening. This discovery has great importance for the South East of the country where early flowering growth can be set back because of the effects of drought. New agrotechnical methods can also help the spread of southern species to the North. Scientists of the Agricultural Institute of the South East USSR are greatly widneing the scope of their tagged atoms research. (Sovetskaya Rossiya, Sept. 15, 1956).

The All-Union Science Research Institute of Grain, together with the Biophysical Institute of the Academy of Sciences of the USSR, has developed a preparatory project for a powerful grain irradiation installation.

The installation is designed for the destruction of insects found in the grain, so that the storage period could be lengthened.

Plans have been made for the choice of the best irradiator configuration as it greatly influences the production capacity of the installation. As a source of gamma radiation, it is planned to use fission products, which are manufacturing waste products.

The installation will have the capacity of working over not less than twenty tons of grain per hour at a dose of 30,000 r. It is planned to have the installation transportable.

FOREIGN SCIENTIFIC AND TECHNICAL NEWS

ON THE DISCOVERY OF THE ANTI-NEUTRON

The anti-proton, the first of heavy anti-particles to be discovered was found, as is known, at the University of California in September-October 1955.* Prof. Sergre reported on this discovery at the All-Union Conference on the Physics of High-Energy Particles in Moscow in May 1956.

On September 15, 1956, the United Press reported that a second heavy anti-particle, the anti-neutron, had been discovered at the same Unversity. We were informed that the anti-neutron was obtained during a cross charging process with the anti-proton.

P. K.

* J. Atomic Energy 1956, No. 1, 119.

PLUTONIUM HEXAFLUORIDE

The properties of plutonium hexafluoride and methods used in its production were discussed and experimental apparatus described in three papers by British and American authors [1-3].

Formation of PuF_6 was observed during the interaction of gaseous fluorine with the trifluoride, tetrafluoride and dioxide of plutonium. These reactions take place with marked rapidity when the temperatures are between 700-750°C. A high product yield is obtained with quick condensation of PuF_6. The table shows a resume of the most important properties of this compound.

Temperature of fusion °C	Temperature of boiling point °C	Heat of sublimation kcal/mole	Heat of evaporation kcal/mole	Vapor pressure mm of Hg	
				from −29.5 to +21°C	from +15 to +60°C
54 ± 1				$\log P = 11.45 - 2.778 \cdot 10^3/T$ [1]	
50.7*	62.3	12.1	7.4		$\log P_{trans} = 7.6923 - \frac{1614.3}{T}$ [2, 3] $\log P_{trans} = 10.841 - \frac{2634.3}{T}$ [2, 3]

* Corresponds to pressure of 511 mm of Hg.

The curve of the vapor pressure of PuF_6 approaches an analogous curve for UF_6. The similarity of the chemical properties of UF_6 and PuF_6 is confirmed by analogous molecular and crystallographic structures of these compounds.

Alpha activity of plutonium brings forth uninterrupted radiation disintegration of the PuF_6 molecule into F_2 and a plutonium fluoride of lower valence. The rate of solid PuF_6 disintegration comes to 1.5% per day; in the gaseous phase it is considerably less and the system can reach a stable state. Heat dissociation of PuF_6 at room temperatures is not noticeable but it was found that at temperatures > 200°C the dissociation is very rapid. Equilibrium dissociation constant for PuF_6 into F_2 and PuF_4 is $1.80 \cdot 10^3$ at 220°C.

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[2] A. Florin and J. Tannenbaum, et. al., ibid, 368.

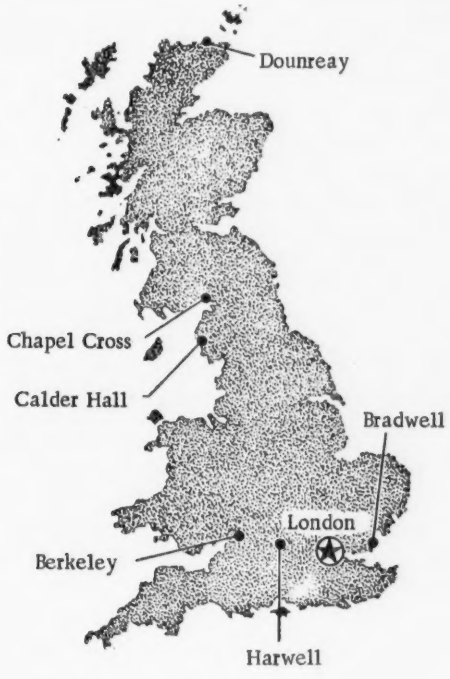
[3] B. Weinstock and J. Malm, ibid, 380.

V. P.

SECOND ANNUAL REPORT OF THE ATOMIC ENERGY AUTHORITY OF THE UNITED KINGDOM

(For the period from April 1, 1955 to March 31, 1956)*

The report states that the past year was marked by a growing interest in England in the development of atomic energy for peaceful uses, which interest is exemplified in particular by the creation in May 1955 of a Council on atomic energy questions whose membership includes representatives of various institutions. The aim of the council is to give an opportunity to scientists and engineers for discussing questions related to the utilization of atomic energy. Many British firms have set up their own organizations to study the uses of atomic energy in industry. For example the company "Associated Electrical Industries" has announced its intention of constructing the first private experimental reactor in Great Britain.



Locations of principal English atomic centers.

During the year being reported, construction was continued on the reactors at Calder Hall (the first British atomic electrostation);** Harwell (reactors "Dido" and "Pluto"),*** also reactor "Lido" earmarked for tests on radiation safeguards and in Dounreay (a reactor for fast neutrons).****

Three new atomic centers are being created: in Chapel Cross, Grove Airfield and in Breaknell. Of the six atomic power stations being constructed by the Atomic Energy Authority with a Calder Hall type reactor, four are being constructed in Chapel Cross, two in Calder Hall. In Grove Airfield new laboratories are projected for radiation technology groups. It is planned to transfer here from Harwell a school for the training of personnel for work with isotopes. Technological workshops and a building bureau will be located in Breaknell. The choice of locations for new atomic centers is also being studied. The announcement is made that the personnel of the Atomic Energy Authority, at the end of the period reported on, numbered 24,000 people.

Britain's principal suppliers of uranium remained as heretofore Australia (ores in Rum Jungle and Radium Hill), the Belgian Congo (ore in Shinkolobwe) and South Africa (ores in the Transvaal and Orange Republic). In order to guarantee future supplementary imports of uranium, supplementary agreements on uranium supplies were signed with these countries.

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* The report in the form of a pamphlet was published by the British Official Documents Press.

** J. Atomic Energy 1956, No. 1, 106; 2, 1, 91 (1957).

*** J. Atomic Energy 1956, No. 3, 141.

**** J. Atomic Energy 1956, No. 2, 106.

Purchases of thorium remained small, which leads one to think that the use of thorium as nuclear fuel is still in the future.

In connection with the construction of the reactors in Calder Hall the need arose for metallic uranium. This need was filled both by an increase in metallic uranium production and the regeneration of irradiated uranium, which after a chemical reworking in Windscale is changed into UF_6 and is sent on to Capenhurst for enrichment.

The report mentions that progress in the operation of industrial reactors was made because of a wide use of periscopes and television cameras for the study of such parts of the reactor as are inaccessible due to high radioactivity.

Great progress was also made in the cooperation of four groups of industrial firms desiring to build atomic power plants. The two first atomic power plants in Berkeley (Gloucestershire) and in Bradwell (Essex) were modeled after the Calder Hall type reactor.

In connection with this, many measures were taken to acquaint representatives of these firms with the plans, construction, and operation of the reactors administered by the Atomic Energy Authority.

To coordinate the work in private development of atomic energy, a committee was created for cooperation in the field of atomic energy consisting of representatives from the four industrial groups and the Authority.

In the field of scientific research, the Atomic Energy Authority plans to study three main fields: uranium-graphite reactors with gas cooling, pressurized water reactors, and sodium cooled graphite reactors. These fields include the study of five types of reactors: fast neutron reactor, homogeneous reactor, reactor with liquid metal fuel, gas cooled reactor (operating at high temperatures in the active zone), and finally a reactor which utilizes organic liquids as a coolant. Intensive research is being carried out in all these three fields.

A great deal of attention has also been given to the improvement of reactor technology. For the blower, bearings were developed in which gas was used as a lubricant. These bearings are used both in the blowers and in pumps for the circulation of liquid coolant. A method has been developed for the obtaining of homogeneous mixtures of beryllium and nuclear fuel, which enables one to prevent the appearance of unwanted porosity which is inescapable in usual baking methods. Another achievement is the preparation, by the method of hot pressure, of uranium fuel elements with a covering made from powdered beryllium. Technology was worked out for the preparation of thorium ingots by cold pressure. Also new heat resistant alloys of aluminum with iron, siliceous nickel and titanium for use as construction materials in nuclear reactors have been obtained.

The production and exportation abroad of radioisotopes have continued to increase. The use of radioactive isotopes has greatly increased in industry, agriculture, medicine, etc. Much work has been done in the field of health preservation and the guaranteeing of safe conditions for the personnel having to work with radioactive radiations.

Yu. K.

OPENING OF THE FIRST BRITISH ATOMIC POWER STATION

The official opening of the first British atomic power station built by the Atomic Energy Authority took place at Calder Hall on October 17, 1956. The first section of the power station, "Calder Hall A" was started with uranium-graphite reactors.

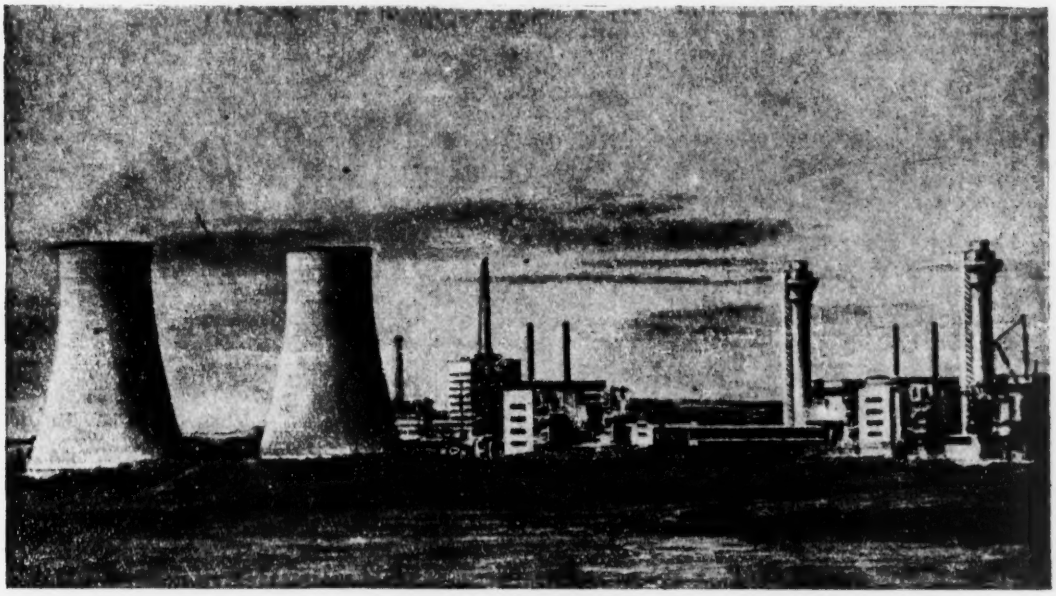

Fig. 1. General view of the atomic power station at Calder Hall. (On the right Windscale industrial reactors).

The second section of the station, "Calder Hall B," which will likewise have analogous reactors, is under construction. The station reactors have a two-fold purpose: i. e., the production of electric power and of plutonium.[1].

In contrast to the first Soviet atomic power plant with an uranium-graphite reactor, started in June, 1952, [2], the Calder Hall atomic power station reactors use natural uranium for fuel; and, for a coolant, carbon dioxide gas under pressure of 6.8 atm, having a temperature of ~ 135°C on entering the reactor and ~ 335°C on leaving it. Steam, generated in the heat exchanger (under two pressures of 13.6 and 3.6 atm) is reheated to corresponding temperatures of 310°C and 171°C. This steam is supplied to four turbogenerators of 23megawatts power each. Thus the total electric power of the first section of the atomic power station comes to 92 megawatts [1].

Scientists from many foreign countries were present at the opening of the power station, among them the Chief Scientific Secretary of the USSR Academy of Sciences, Academician A. V. Topchiev.

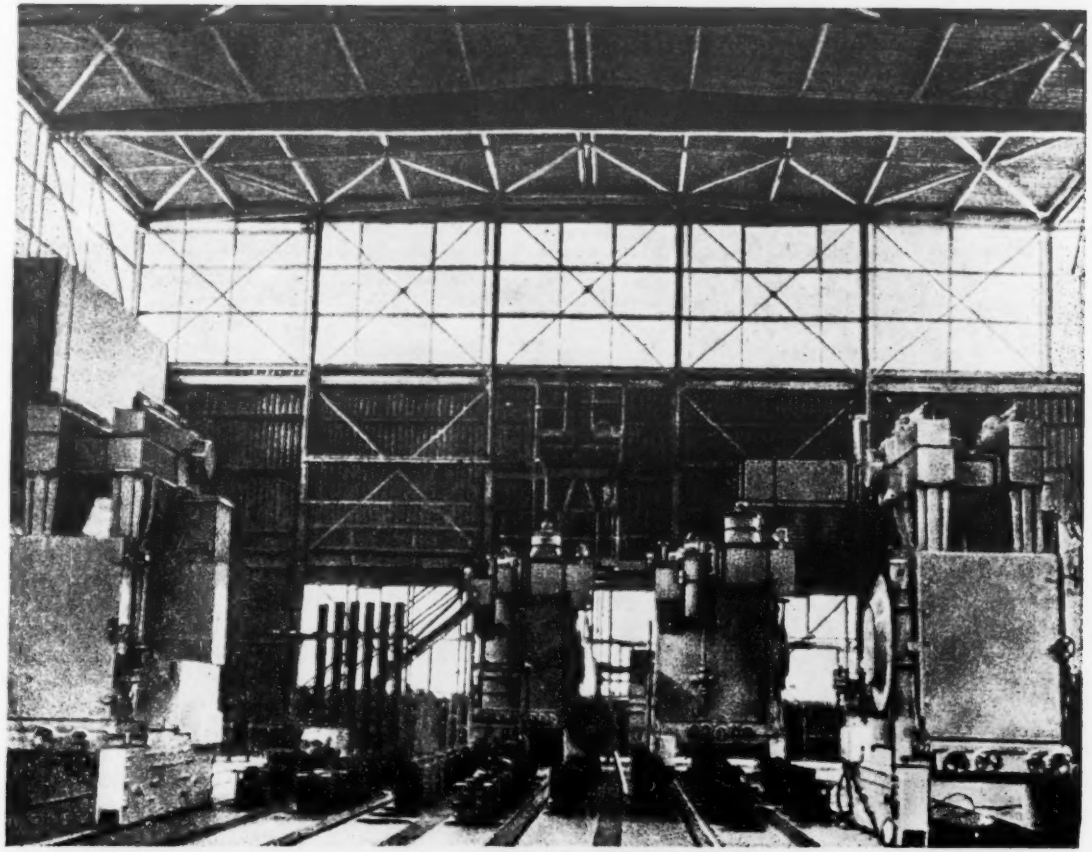

Fig. 2. Loading room of the Calder Hall atomic power station reactor. In the foreground two loading machines with light shielding. In the background two unloading machines with heavy shielding.

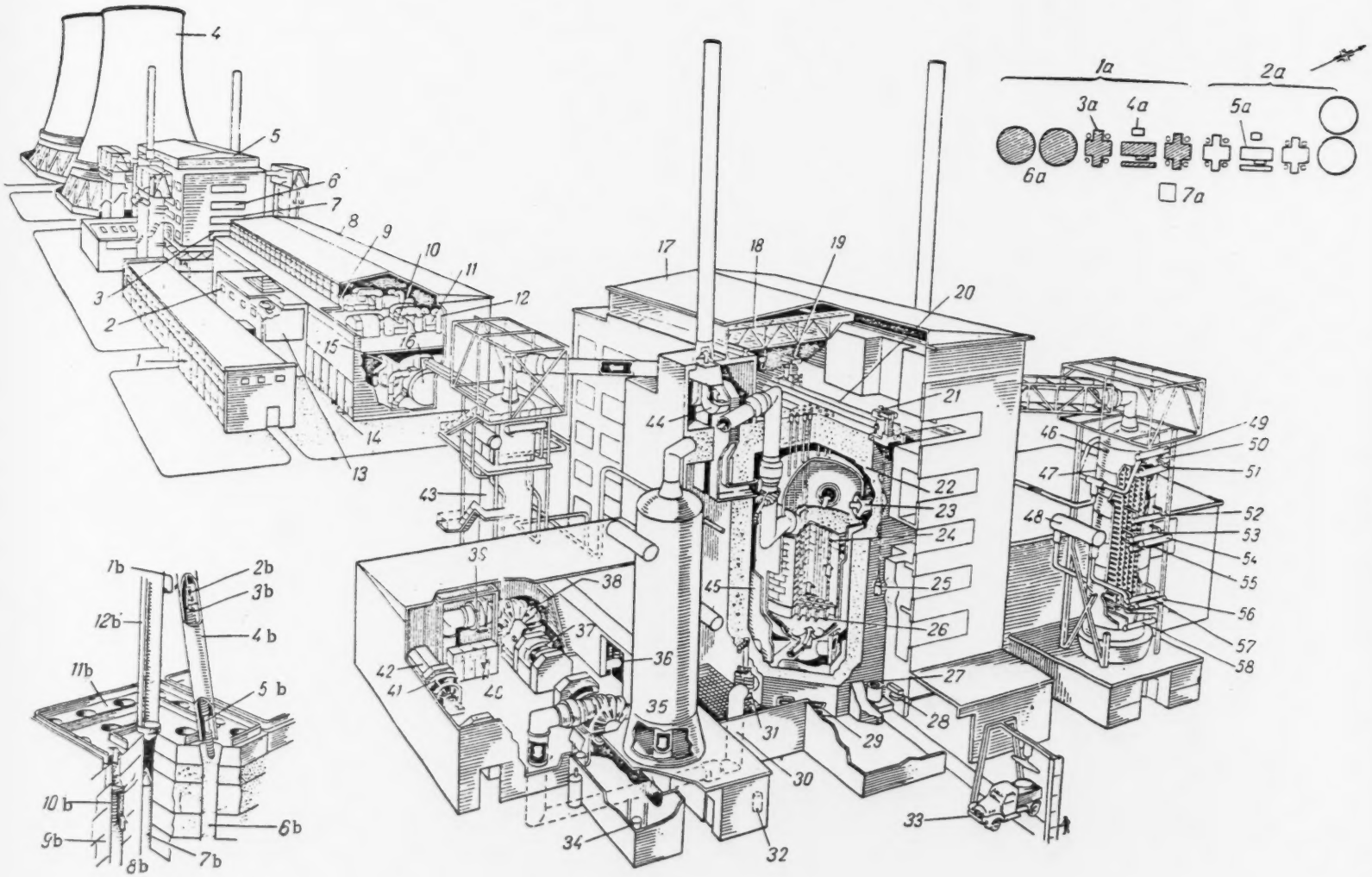
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Fig. 3. Schematic Section of the Calder Hall Power Station.
1) Administrative section; 2) batteries; 3) control room; 4) cooling tower (evaporator); 5) reactor No. 1; 6) room for preparation of nuclear fuel; 7) room for taking gas samples; 8) turbine hall; 9) generator; 10) low pressure turbine; 11) high pressure turbine; 12) main pipe line high pressure steam; 13) commutator room; 14) transformers; 15) turbine condenser; 16) steam condenser; 17) reactor No. 2; 18) travelling crane; 19) loading machine with light shielding; 20) tracks for the loading-unloading machines; 21) unloading machine with heavy shielding (above the unloading well); 22) biological shielding (2 m thick); 23) hot gas exit; 24) fuel rod (enlarged for clarity); 25) bucket for unloaded fuel rods; 26) supporting grill (active zone); 27) fuel rod container; 28) container lid; 29) entrance point of cooling air; 30) entrance point of coolant into reactor; 31) wedge-shaped bolt of first shell; 32) high pressure circulating pump (8 for each reactor); 33) container with discarded fuel rods, sent to Windscale for reworking; 34) low pressure circulating pump (8 for each reactor); 35) exit point of coolant from reactor; 36) oil tanks, refrigerators and pumps; 37) dc electric motors; 38) air blower for CO_2 with 1500 kw electric motor; 39) suspended expansion joint; 40) control panel; 41) dc generator; 42) ac electric motor; 43) heat exchanger; 44) suction ventilator for cooling air; 45) steel shield for thermal neutrons (7.62 cm thick); 46) supercharger for high pressure steam; 47) high pressure steam line to the turbine; 48) low pressure steam.tank; 49) collector for emerging supercharged high pressure steam; 50) high pressure steam tank; 51) entering collector supercharged high pressure steam; 52) entering collector for high pressure steam generator; 53) entering collector of high pressure economizer; 54) exit collector of supercharged low pressure steam; 55) entering collector of supercharged low pressure steam; 56) exit collector low pressure steam (from the mixing economizer); 57) entrance collector of low pressure steam generator; 58) entrance collector of high pressure steam generator (to the mixing economizer).

Plan of the Atomic Power Station Layout.
1a) First section of power station "Calder Hall A;" 2a) Second section of power station "Calder Hall B;" 3a) reactor; 4a) building for storing CO_2; 5a) Turbine Hall; 6a) coolant towers (evaporator); 7a) substation.

Loading Method.
1b) Directional angle of the filling unit; 2b) holder; 3b) spiral ribs; 4b) chute for feeding of fuel rods, one by one; 5b) uranium; 6b) opening for fuel rods (16 in each group); 7b) control rod in central opening; 8b) gas direction, from bottom up; 9b) graphite blocks; 10b) opening, filled with fuel rods; 11b) steel plate; 12b) pipe (cross section) through which is brought in the control rod.

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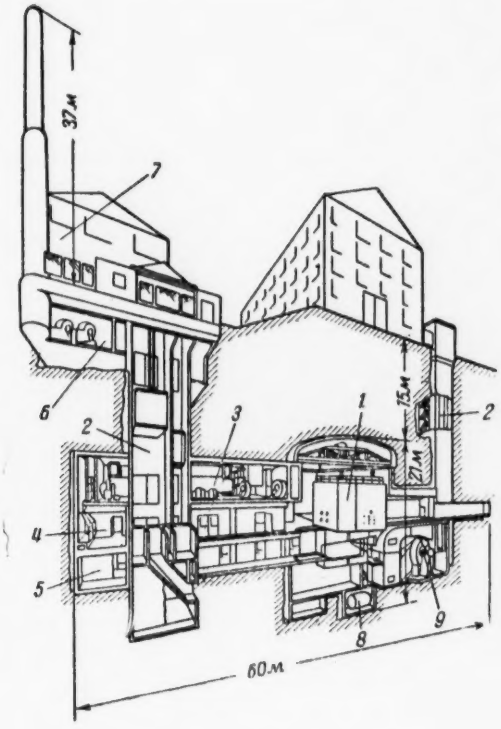
[2] J. Atomic Energy 1956, No. 1, 10.(T.p. 7).*

Yu. K.

* T.p. = C. B. Translation pagination.

ATOMIC ENERGY DEVELOPMENT PLANS IN SWEDEN

Annual energy requirements in Sweden for 1955 were calculated at 24 million tons of coal [1]. Less than 27% of the energy requirements could be covered by their own energy sources (hydrostations and coal). More than 73% of energy requirements had to be met through imports of oil, coal and coke.



Schematic layout of reactor "R-1" and its auxiliary equipment. 1) Reactor; 2) shafts; 3) ventilating installations; 4) chemical laboratory for work on radioactive materials; 5) radioactive sample storage; 6) radioactive waste storage space; 7) chemical laboratory for extraction of plutonium and disintegration products from fuel rods; 8) storage tanks for heavy water; 9) blower for cooling of the refrigerant (Heavy water).

If we base our calculations on the average increase in the rate of energy consumption, which amounted to 4-5% between 1945-1955, then annual energy consumption for 1975 will reach 52 million tons of coal. Only 20% of this will be covered by an expansion of hydroelectric resources and approximately the same amount by native fuel resources.

Therefore a great deal of attention is now given in Sweden to the development of atomic energy, especially as there are uranium deposits in the country. In spite of the low uranium content in the ores it can be used, and with modern technological methods it would be possible to extract, from the existing uranium deposits, energy equivalent to at least 1.5 billion tons of coal.

The Council for Swedish Power Industries, together with a number of other organizations, announced at the end of 1955 its intention of building two atomic power stations ("Adam" and "Eve") at a total cost of 40 million dollars [3]. The first of these, with a thermal power of 75,000 kw, situated within 60 miles of Stockholm and destined for providing heat will be started in 1960. The second one, with a power of 100,000 kw for the production of electric power will be built in the hills of Southern Sweden. The reactors in these stations will be run on native uranium. Heavy water will be used as reactor moderator and its production, through a new technological methods, will be undertaken by a Swedish concern [4]. The power station equipment will be mainly of Swedish manufacture.

Plans for the construction of four additional power stations were published a month after the original announcement [2]. The first of these, "R-3a," also earmarked for heat production, will furnish industry with 90 megawatts of heat, starting in 1960. Station "R-3b" an improved variation of the former, will be built a year or two after R-3a is in operation; its thermal power will be 71 megawatts; its electric power 13 megawatts. The third station will have electric power of 75 megawatts. The last one, with electric power of 300 megawatts, will not be finished before 1967.

The program for atomic energy development in Sweden takes into consideration that by 1965 the power of atomic installations will reach 800-1000 megawatts, which will permit the saving of 100,000 tons of coal; by 1970, 3,000-6,000 megawatt (savings of 1 to 3 million tons of coal, and by 1975, 6,000-12,000 megawatt (savings of 3 to 8 million tons of coal).

It is estimated that the cost of atomic power station produced electricity will be 2-4 öre* a kw hour [4], which is a bit higher than that of electricity produced by hydroelectricstations which now costs 2.5-3 öre, and lower than the present cost of thermal station electricity, which is 5-7 öre. For heat production, atomic stations will be able to compete successfully with stations operating on ordinary fuels; the cost per kw hour of thermal energy will be 1.2-2.4 öre in atomic power stations and 2.0-2.6 in ordinary stations.

There is in operation at the present time one research reactor in Sweden (Stockholm) built underground at a depth of 35 m [5]. A second research reactor ("R-2") with thermal power of 20 mw, for radiation testing of materials, is being built on the shores of the Baltic Sea. This reactor will be started in 1959.

LITERATURE CITED

[1] Engineering 179, No. 4655, 462 (1955).

[2] Engineer 201 No. 5239, 736 (1956).

[3] Nucleonics 14, No. 1, 15 (1956).

[4] Nucleonics 13, No. 12, 15 (1955).

[5] Nucleonics 13, No. 10, 15 (1955).

V. A.

* An öre is 0.01 of a krona.

BRIEF COMMUNICATIONS

India. The first reactor in Asiatic countries was started in August 1956 at the Indian Atomic Research center on Trombay Island near Bombay. This reactor of the swimming pool type, or enriched uranium (furnished by Great Britain) was built in one year by Indian specialists. A reactor of the Canadian type NRX is to be started in 1957 at Trombay Island. According to the agreement reached in Colombo, the Canadian Atomic Energy Commission will help with the construction of this reactor [1].

India has deposits of raw material for the obtaining of fissionable materials. A factory in Travancore-Cochin has been extracting thorium and uranium from monazite sand for four years. Construction of several other factories has been planned for the reworking of nuclear raw materials and also a factory for the production of heavy water (in the Punjab) [2].

[1] Nuclear Power 5, 195 (1956); [2] Nuclear Power 3 103 (1956).

Japan. 75 miles north of Tokyo, in Tokai-Mura, the construction of an atomic research center has been started. At the corner stone laying ceremonies of this center, the chairman of the Japanese Atomic Energy Commission, Matsutaro Shoriki, announced that the 15-year program for the development of atomic energy in Japan includes the construction of eight reactors. The first two reactors will be obtained from the USA. [Nuclear Power 5, 197 (1956)].

Turkey. According to a communication from the Turkish Institute of Mineral Resources, uranium deposits were found near the town of Yozgat some 100 kilometers east of Ankara [1]. Previously uranium mineralization had been known to exist in the region of the hydrothermal copper deposits in Ergani [2].

[1] Mining World 3 (1956); [2] Jaderná Energie 4 (1956).

Sweden. In the region of Göteborg uranium deposits have been discovered in shale with a 0.03% of uranium. The deposits are tentatively estimated at 1 million tons of uranium. There are no data on the possibility of practically using such low grade ore. Deposits of an analogous type of uranium in dictyonema (graptolite) shales of Sweden are well known. However, being characterized by a low metal content, they are not at the moment exploited and are used only for carrying out of technological investigations. The newly discovered deposit is estimated to be the largest of all the uranium deposits in Swedish shales and judging by the brief communication may well prove to be richest in uranium. [Nucleonics 14, 1 (1956)].

Canada. Along with the rapid growth of the previously descovered uranium deposits in the new uranium bearing region of Canada, Blind River, prospecting which has spread in an easterly direction along the uranium bearing belt, has brought about the discovery of a new uranium bearing region in Labrador.

The new uranium bearing region takes up 1800 square kilometers and is 136 kilometers long. Uranium minerals, among which the most widely disseminated is uranium (smolka) are found not only in sedimentary layers but also in granites. Uranium bearing layers stratographically parallel the ore bearing strata of the Blind River and Beaver Lodge regions.

Uranium mineralization was first noticed here in 1954 south of Makkovik. In the process of subsequent surveys twenty radioactive spots were found, of which six contained uranium. In 1955 within 120 km of Monkey Hill uranium (smolka) was found in association with native ore, silver and mineral copper. Individual ore samples contained from 4.25-5.5% uranium. Industrial significance of these new discoveries is as yet not clear. [Ann. mines 6, 149 (1956)].

USA. A plan for the construction of the first atom powered vessel has been approved in the USA. It has not yet been decided whether it is to be a passenger ship, a merchant vessel or a tanker. The design and construction of the ship itself will be carried out by the Department of the Navy, and the power installation by the Atomic Energy Commission. In Pittsburgh, at the Westinghouse Company plant, work is being carried out on the development of a reactor for a large vessel (A1W). The approximate cost of building such a vessel is placed at 42.5 million dollars. Presumably the construction of the vessel will be finished by 1960. [Nuclear Power 5, 198 (1956)].

USA. An experimental installation was put into operation at the Oak Ridge National Laboratory for the extraction (according to a method developed at that laboratory) of radioactive isotopes of cesium (Cs^{137}) from disintegration products. Special cartridges 3 cm in diameter, 3.5 cm high and weighing approximately 90 g are filled with the obtained cesium chloride. Three such cartridges, packed in a cassette with double walls of stainless steel, represent a source with activity of 2000 curies. The installation will produce 200,000 curies a year, which will bring about a marked lowering of existing prices of radioactive sources. Besides cesium-137 the Oak Ridge Laboratories contemplate the extraction from disintegration products of other radioactive isotopes: strontium-90, cerium-144, promethium-147, technicium-99 and ruthenium-106. The first cesium-137 source of 2000 curies will probably be used at the University of Michigan. At the present time in the USA there are about 1000 industrial firms using radioactive isotopes in 1347 different installations. [Nuclear Power 5, 198 (1956)].

USA. Over a period of years, prospecting for uranium ore beds has been going on in the territory of Alaska. Up until 1955 this prospecting did not produce any practical results; single finds of uranium containing minerals had only scientific interest.

In May 1955 in Alaska the first bed was found which attracted the attention of industrial organizations. This bed is within 3 km of Hessa Lake on the southern slopes of the Bokan Mountain ridge on the Prince of Wales peninsula.

As far as one can judge by the brief information, the uranium ore is related to basic strata of the diorite-porphyrite type. It is developed in the zone of hydrothermal changes of the strata along precontacted parts of pegmatities where feldspars are replaced by mineral ores. Uranium mineral–uranium titanate (brannerite or davidite).

Analysis of individual samples of the ore (no doubt the richest ones) gave the contents of U_3O_8 up to 1-3%. [Uranium Magazine 4 (1956)].

German Federal Republic. The West German firm "Rhein-Westphalische Elekhizitäts Gesellschäft" announced its intention of obtaining a nuclear reactor. Offers to supply such a reactor have been received from the USA and Great Britain. As indicated, acquiring of the reactor follows up the aim of accumulating experience in its use so that in the next ten years a reactor could be built with a power of 700-1000 megawatts. According to the program for atomic energy development the total power of nuclear reactors in the German Federal Republic should reach 2.8-3 million kw by 1975. [Nuclear Power 5 (1956)].

Great Britain. After consultation with the Atomic Energy Authority of Great Britain, the South of Scotland Electricity Board concluded it was necessary to build an atomic power station to supply electric energy to that region. The station will consist of two reactors with a graphite moderator and gas cooling and will have an electric power of 250-300 megawatts. Although the exact location of the station is not given, it will be determined by the center of electric energy consumption on the shores of Ayrshire. This station will take care of one-fourth the consumption of electric energy in Southern Scotland and will permit a saving of approximately a million tons of coal a year. It is interesting to note that the question is being studied of using, at the atomic station, heat accumulators, the filling of which with hot water would take place between peak loads in the electric network. [Nuclear Eng. 8, 210 (1956)].

France. According to information on hand, France can increase her uranium production four-fold within the next three years. The thorium beds in Madagascar make France one of the countries possessing large reserves of atomic raw material. After the ore has been worked, France will not only be completely independent of fissionable material imports, but will be able to become an exporter of them herself. [Nuclear Eng. 8, 211 (1956)].

REVIEWS AND BIBLIOGRAPHY

ANNOTATIONS

"Isotopes"

Prospectus of the United Government Trust "SOYUZREAKTIV" (in press)

The prospectus gives a list of radiation sources, products and compounds with radioactive and stable isotopes which are to be produced in 1957 through the United Government Trust, "Soyuzreaktiv."

In the assortment are included both those products which have been used in manufacturing and those earmarked for experimental production.

The prospectus has been arranged in subdivisions for the sake of systematization of the material.

The properties of 69 radioactive isotopes have been briefly described in the first section and a listing given of 296 compounds with an indication of specific activity and standard doses.

The second section deals with radiation sources. It gives, together with a description of separate sources, their activity, form and geometry, a brief description of isotope properties.

In the third section, "Enriched Stable Isotopes and Compounds with Enriched Stable Isotopes" there is a list of 240 compounds of stable isotopes.

A special fourth section is given over to descriptions of the appearance, packaging,and types of containers used in the transportation of radioactive products to the place where they are to be used.

The introduction gives general rules for planning applications, valid order, closing of contracts and delivery of products. Application blanks are included with the prospectus.

A leaflet with the prospectus includes charges for all produced forms adaptable to manufacturing.

As these charges will be probably lowered in the near future a new leaflet will take its place indicating the new price ranges.

This prospectus is not a reference source for technical properties of isotopes, but serves to acquaint a great number of people, those working directly with radioactive and stable isotopes and those concerned with supply questions, with the 1957 list.

Detailed technical properties of isotopes, their compounds, products and radiation sources will be given in an isotope catalogue to be published during the first half of 1957.

A. I.

REVIEWS

"Nuclear Reactors"

(USA Atomic Energy Commission Material)

In view of the approaching Geneva Conference, the USA Atomic Energy Commission prepared in the spring of 1955 a set of eight volumes dealing with atomic energy and its application, based on work done in the USA

during the period of atomic program implementation. The American delegation presented copies of this set to all the delegations of the member-nations, including the delegates of the USSR at the International Conference on the Peaceful Uses of Atomic Energy held in Geneva in August 1955.

The set consisted of the following volumes:

1. Research Reactors.

2. Nuclear Reactors, part I. Physics of Nuclear Reactors.

3. Nuclear Reactors, part II. Technology of Nuclear Reactors.

4. Nuclear Reactors, part III. Materials for Nuclear Reactors.

5. Graphical Atlas of Neutron Cross Sections for Elements.

6. Chemical Processes and Equipment (description of factory technological process for the reworking of spent fuel elements and description of various equipment for work with radioactive materials).

7. 8 Years' Summary on Isotope Use.

8. Papers on Atomic Energy (bibliographical, reference, information).

The USA Atomic Energy Commission entrusted the writing and editing of these volumes to the most important physical science centers in the USA namely the Argonne, Oak Ridge, Bookhaven National Laboratories, Los Alamos Laboratory, the Knolls Atomic Energy Laboratory, and the University of California.

By the titles alone we can see the great width of the scope of questions treated in the series; it includes all basic problems connected with the research, production and application of atomic energy. It must be noted, that in methods of presentation and preparation of the material the separate volumes differ considerably one from the other and that the series in itself is therefore not a homogeneous whole. Thus the first volume – Research Reactors – was written specially for this set during 1954-55 and contains relatively new material, whereas the next three volumes on nuclear reactors and also volume 6 were published in a classified manner in the USA in 1952-53; early in 1955 they were declassified and reissued without any changes (discounting several cuts which were made at the request of the censors). The fact remains that they contain a number of previously unpublished data and information, which have definite interest. Further, volume 5 (Geographical Atlas of Neutron Cross Sections) contains data on measurements taken before 1955, among them Soviet ones given by the USSR Academy of Sciences at the request of the publishers.

Volumes 7 and 8 (as well as 1 and 5) were especially prepared for this series and essentially contain various bibliographical reference material on papers published in the USA on atomic energy, nuclear physics and technology.

Foreign Literature Press has prepared a Russian translation of these volumes and it has recently appeared in print.

Volume 5 is not published in a Russian edition as the USSR Academy of Sciences Press published in 1955 an analogous atlas. The data presented conform practically with that in the American atlas. Tables for thermal neutron cross sections from this volume are included in the Russian edition of volume 2.

Let us briefly summarize each volume.

Research Reactors

Presently operating American reactors used for various nuclear physics and technological research are thoroughly described from an engineering point of view. All of these reactors operate on thermal neutrons. Data are given on the operation, properties, and construction of reactors, with the use of plans and diagrams of various parts, details and equipment, graphs, and tables. The majority of these data have been published for the first time. Theoretical and computational data, on which the development of the described reactors was based, is missing.

Nuclear Reactors, part I. Physics of Nuclear Reactors.

This volume consists of two parts. The first and larger part describes the physical processes in nuclear reactors. Here is given the basic necessary information on nuclear physics and on nuclear research methods, the theory of reactor operation, together with known experimental data.

Tables on the properties of isotopes appearing in this volume have been omitted from the Russian edition as being out of data, and also because more recent tables, published in the "Reviews of Modern Physics" (and greatly supplemented with new data) were published in 1956 by the Foreign Literature Press.

The second smaller part is given over to radioactive radiation shielding. Much valuable scientific and technical information isgiven here on the calculation of shielding and the application of materials to this end.

Nuclear Reactors, part II. Technology of Nuclear Reactors.

The basic problems of reactor technology, namely the question of reactor cooling and methods of using nuclear fuel, are discussed in this volume. Thus various types of reactors are described in detail, classified according to coolants (ordinary and heavy water, liquid metals, gases),and by methods of nuclear fuel introduction (uranium salts solution, molten mixture of uranium with other metals and molten uranium salts). Control and management of reactor operation and principles of design of various type reactors are briefly described. At the end of the volume there are short tables of nuclear constants. The volume has many illustrations, sketches, graphs, photographs, etc.

Nuclear Reactors, part III. Materials for Nuclear Reactors.

The properties of elements, alloys, compounds and technical materials used in the construction of reactors as building materials and in their operation as nuclear fuel, moderator, reflector, etc. are fully described from various points of view in this volume. Information is given on the extraction and production of these materials; on their physical, chemical,mechanical, and corrosive properties; equipment, preservation and methods of producing manufactured items from them. Only solid materials are discussed.

In the Russian translation certain changes and corrections according to contemporary sources have been included. This applies in particular to trans-uranium elements. In the introduction to the American volume, plans are mentioned for a new edition taking results over the past few years into consideration.

Chemical Processes and Equipment

This volume consists of two parts. The technological process of industrial reworking of spent fuel elements is described in the first part and inclues the description of equipment; methods of deactivation; questions of shielding; questions of production economics; the analytical division of the factory. In the second part of the volume the "hot" laboratory is described. The special laboratory equipment which is necessary to safeguard work with radioactive materials (optical apparatus for observation, various manipulators, measurement apparatus with remote control, containers, transportation means, etc.) is here described in detail.

Eight Years' Data Summary on Isotopes

In the beginning of this volume there is a short popularly written resume of isotope properties and methods of using them in various practical and scientific ways in biology and medicine, in chemistry and physics, in technology and agriculture; questions of experimental techniques and radiation shielding are also briefly touched upon. Complete systematized lists of articles, papers, surveys and such on the subject of isotopes and their many uses occupy the main section of this volume. Data are given on the distribution of radioactive and stable isotopes produced in the USA and their use in medicine.

Papers on Atomic Energy (Bibliographical Reference Information)

This volume includes:

1. Bibliography of papers given at the International Conference on the Peaceful Uses of Atomic Energy in Geneva in August 1955.

2. Full biographical-reference data on all scientific and technological research published in the form of articles, reports, surveys and monographs from 1954-1955 by the USA Atomic Energy Commission.

3. Index of USA Atomic Energy Commission and other related organization publications for that same period.

All the volumes published in the Russian edition have appeared without any changes (except for those small additions and corrections mentioned above).

From the above descriptions it is easy to see that each separate volume and the entire set itself will be very useful to a large circle of our specialists: scientific workers, engineers, school instructors (who are connected through their work with questions discussed in these volumes), and also students and fellows from similar faculties, publishing and library workers serving these scientific institutions.

Publication of a series of books on American materials will permit Soviet readers to get better acquainted with the work carried on in the USA in the field of atomic energy.

A. Gusev

LIST OF NEW LITERATURE ON THE PEACEFUL USES OF ATOMIC ENERGY

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CONTENTS

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